Water Quality Modeling
Technical Appendix
Integrated Storage Investigations
In-Delta Storage Feasibility Study

Draft May 2002

Delta Modeling Section
Modeling Support Branch
Office of State Water Project Planning
Department of Water Resources

FOREWORD

The CALFED Record of Decision (ROD) has identified the In-Delta Storage Program as a potential project to be pursued for improvement in Delta water quality and enhancement of water supply flexibility. Stage 1 of the ROD requires that feasibility studies be conducted to select and recommend a project alternative by December 2001.

The Office of State Water Project Planning's Delta Modeling Section was tasked with conducting a water quality modeling evaluation of the proposed In-Delta Storage project. Modeling tasks were conducted by the Delta Modeling Section in coordination with the U.S. Bureau of Reclamation and the Department of Water Resources' Division of Planning and Local Assistance.

This technical appendix is a loose compilation of key reports and memorandums that summarize elements of the water quality modeling work that were completed in support of the In-Delta Storage Feasibility Study. Please refer to the following report for additional technical documentation on model development and validation conducted in support of the study: *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, Twenty-Second Annual Progress Report to the State Water Resources Control Board, August 2001.*

Paul Hutton
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OFFICE MEMO

TO: Tara Smith	DATE: April 18, 2002
FROM: Michael Mierzwa	SUBJECT: DSM2 Evaluation of In-Delta Storage Alternatives

1 Introduction

DWR's Integrated Storage Investigations (ISI) is reviewing the Delta Wetlands proposal to convert two Delta islands, Bacon Island and Webb Tract, into reservoirs and to restore two other Delta islands, Bouldin Island and Holland Tract, as wetland habitats. The two reservoir islands (referred to as the "project islands") would be used to store water during surplus flow periods. This surplus water would later be released for export enhancement (i.e. increases in State Water Project pumping) or to meet Delta flow/water quality requirements. ISI has re-engineered the Delta Wetlands originally proposed project, and the new ISI proposal was the basis of these DSM2 simulations. The project will be referred to as the In-Delta Storage project to distinguish it from the original Delta Wetlands proposal.

Two 16-year daily hydrologies, one representing current operations (the base case) and one representing projected operations of the project islands, developed using CALSIM II were used as the input for DSM2-HYDRO and QUAL. CALSIM II also provided the releases and diversions to the project islands. The study period was from 1975 to 1991.

The most recent version of the DSM2 geometry was used. The physical specification for the project islands and habitat islands were provided by ISI. A complete record of stage and EC at Martinez were used by HYDRO and QUAL respectively, and dissolved organic carbon (DOC) at the Sacramento River, San Joaquin River, Eastside stream, and Yolo Bypass boundaries were developed for use in QUAL. QUAL was modified to account for DOC increases due to storage retention based on Jung (2001a), and then used to simulate EC and DOC.

This report includes the descriptions of the two scenarios and the results of these DSM2 simulations at four M&I intake locations: Contra Costa's Rock Slough intake near the Old River, Contra Costa's Los Vaqueros intake on the Old River, the State Water Project (SWP) and Central Valley Project (CVP) intakes at Banks and Tracy. Using QUAL's simulated EC and DOC, ultraviolet absorbance at 254 nm (UVA) and the formation of total trihalomethane (TTHM) and bromate at these locations were calculated. Finally, DSM2-PTM (Particle Tracking Model) was used to study the flow patterns associated with the project releases.

2 Description of Scenarios

The two different scenarios were based on CALSIM II output. The base case simulated the Delta without the operations of the proposed In-Delta Storage project. The project alternative included the proposed operations of Bacon Island and Webb Tract and the planned operation of the two habitat islands, Bouldin Island and Holland Tract. Brief summaries of both scenarios are described below in Table 2.1, followed by more detailed descriptions of these assumptions.

Table 2.1: Summary of Planning Scenarios.

	Base: ***No Action***	***Alternative:*** ***In-Delta Storage Operations***
Delta Wetlands Project Islands	No.	Yes. (Bacon Island and Webb Tract.)
Delta Wetlands Habitat Islands	No.	Yes. (Bouldin Island and Holland Tract.)
Boundary Flows	Daily CALSIM II output: base study.	Daily CALSIM II output: alternative study.
Boundary Stage	15-minute planning stage.	15-minute planning stage.
Ag Flows	2020 lod DICU.[1]	Modified 2020 lod DICU.[2]
Martinez EC[3]	CALSIM II Net Delta Outflow & G-model.	CALSIM II Net Delta Outflow & G-model.
Tributary Boundary EC	CALSIM II output.[4]	CALSIM II output.[4]
Martinez DOC	N/A	N/A
Tributary Boundary DOC[5]	Monthly planning data.	Monthly planning data.
Ag Return Quality	MWQI[6] data.	MWQI data, w/ increases in project island DOC based on storage time.[7]

1 - The Delta Island Consumptive Use (DICU) model was used to calculate diversions and return flows for all Delta islands based on a 2020 level of development (lod).

2 - The diversions and returns from the project and habitat islands were modified to better represent land use changes for these islands due to the project operation for a 2020 lod.

3 - Net Delta Outflow based on the CALSIM II flows was used with an updated G-model to calculate Martinez EC (see Ateljevich, 2001a).

4 - CALSIM II calculates monthly EC for the San Joaquin River, which was then converted to daily EC using the monthly EC and flow for the San Joaquin River. Fixed values are used at the other major tributary boundaries.

5 - Based on data collected as part of the DWR-MWQI[6], a new set of boundary DOC data for the major tributary boundaries were calculated (see Suits, 2001a).

6 - Municipal Water Quality Investigations (MWQI).

7 - DOC concentration increases while water is stored on the project islands as discussed in Jung (2001a).

2.1 No Action (Base Case):

CALSIM II was used to provide the tributary boundary flows and exports (including CCWD's Rock Slough diversion, SWP's Banks exports, and CVP's Tracy exports).[8] CALSIM II also provided the Delta Cross Channel (DCC) position. Normal gate and barrier configurations were based on the proposed operation schedule for the South Delta Permanent Barriers (which include Old River at Head, Old River at Tracy, Middle River, and Grant Line Canal). The Suisun Marsh Salinity Control Gate was operated according to previous DSM2 planning studies.
The Delta Island Consumptive Use (DICU) model was used to create 2020 level of demand diversions and returns. Martinez EC was calculated using Net Delta Outflow (as provided by CALSIM II) and an updated G-model (see Ateljevich, 2001a). DWR-MWQI observations were used to create synthetic time series for DOC (see Section 3.2) at the following tributary boundaries: San Joaquin River, Sacramento River, and the Eastside streams. Sacramento River data were then also applied as the boundary conditions for the Yolo Bypass. The flux of DOC from the downstream boundary at Martinez (the sea) was considered insignificant. Details on the development of agricultural return DOC data for DSM2 based on the MWQI observations are described in the report *Revision of Representative Delta Island Return Flow Quality for DSM2 and DICU Model Runs* (Dec. 2000) as prepared by Marvin Jung and Associates, Inc.

2.2 In-Delta Storage Operations (Alternative):

CALSIM II determined the diversions to and releases from the project islands, in addition to optimizing the exports at both the Banks (SWP) and Tracy (CVP) Pumping plants by using the additional system storage provided by the project islands. CALSIM II did separate the storage, diversions, and releases between the two project islands. Priority was given to Bacon Island, by filling and releasing water from Bacon Island before Webb Tract.

The total diversion to each project island is shown in Figure 2.1 (note: this is diversion for each individual island). The larger diversions are winter diversions of surplus Delta water to be released and exported by the Banks (SWP) or Tracy (CVP) Pumping plants later. The smaller off-season diversions are used to "top-off" the project islands in order to account for evaporation losses during the storage period.

[8] CALSIM II does not model the diversion split between CCWD's Rock Slough and Los Vaqueros Reservoir intakes. The CCWD Rock Slough diversions represent both the Rock Slough and Los Vaqueros demands; however, in DSM2 this combined diversion currently is simulated only at Rock Slough.

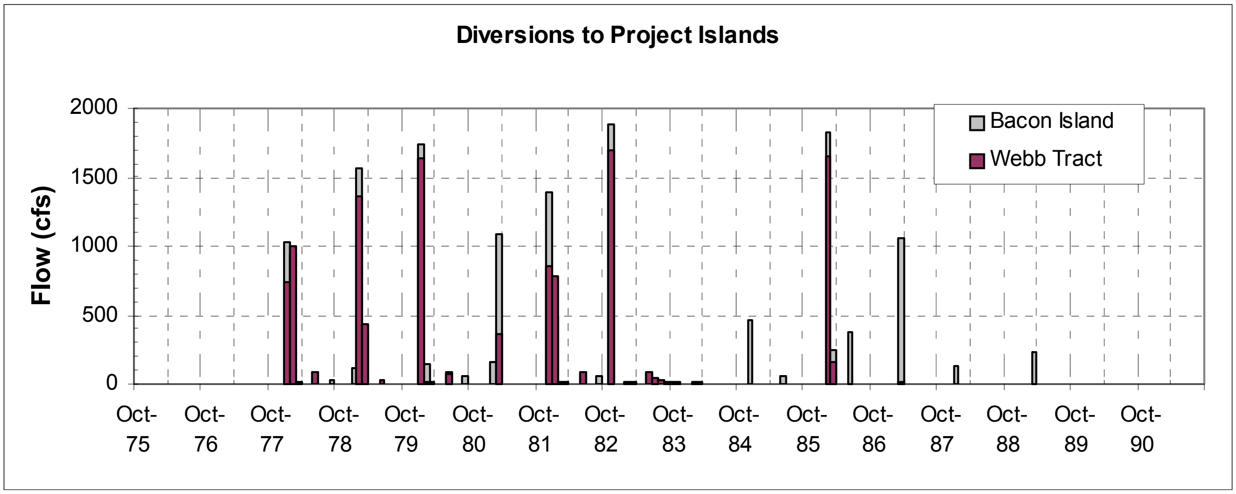

Figure 2.1: Diversions to In-Delta Storage Project Islands.

The total release from each project island is shown in Figure 2.2. Many of the summer project island releases are constrained by amount of water stored in the project islands.

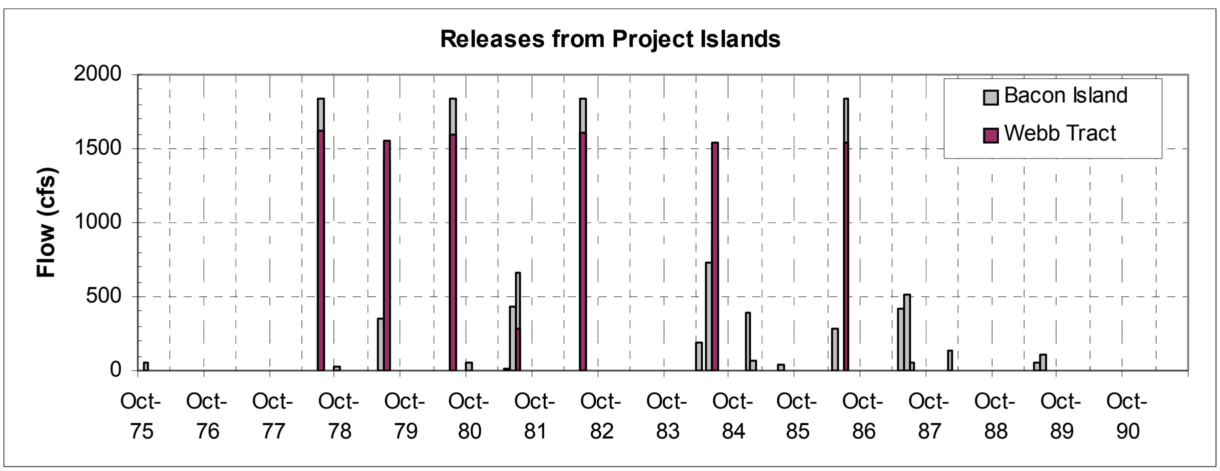

Figure 2.2: Releases from In-Delta Storage Project Islands.

2.2.1 Project Island Configuration

The configuration of the project islands as modeled by DSM2 is listed in Table 2.2. The storage capacity, surface area, discharge location, and both intake / release siphon locations for the project islands were provided by ISI. Each island is designed to use two reversible siphons to divert water onto and later off each island. The diversion and release schedules provided by CALSIM II were divided equally between each island's siphons. The location of the siphons is shown in Figures 2.3 and 2.4. The surface area of each island is fixed in DSM2. The surface area was chosen such that when full, each island would have a maximum depth of approximately 20 ft.

Table 2.2: DSM2 Configuration of Delta Wetlands Project Islands.

Island	*Storage Capacity (TAF)*	*Surface Area (acres)*	*Siphon #1 DSM2 Node*	*Siphon #2 DSM2 Node*
Bacon Island	120	5,450	128	121
Webb Tract	118	5,370	40	103

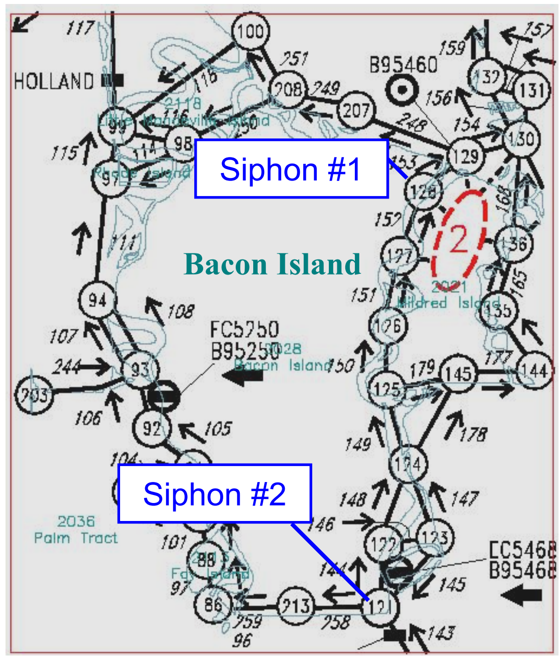

Figure 2.3: DSM2 Representation of Bacon Island.

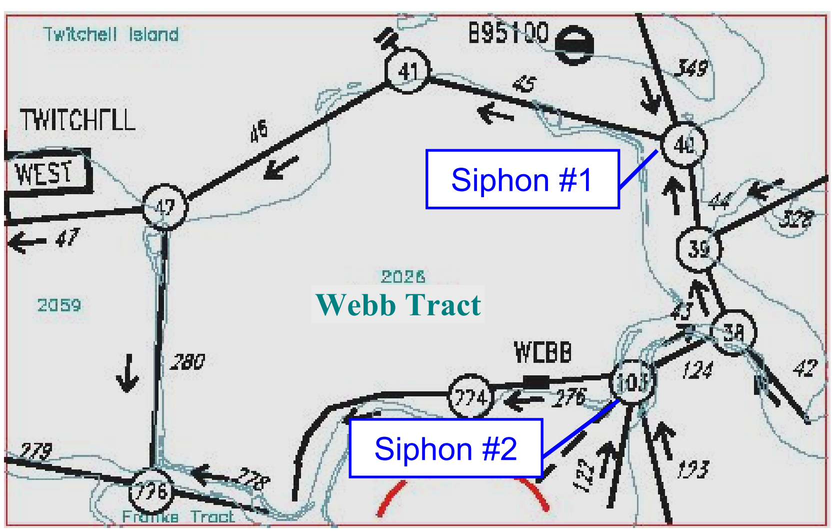

Figure 2.4: DSM2 Representation of Webb Tract.

The volume of water stored in each island reservoir is a direct function of the amount of water diverted into or released from each island. Volume of a reservoir in DSM2 is the product of the reservoir's surface area (listed above in Table 2.2 for the project islands) and its current stage level. The project islands were isolated from the Delta channels, thus there was no limit to the stage in either reservoir. In order to prevent drying up of the island reservoirs an additional 0.2 ft of water was assumed to be present on both islands at the beginning of the simulation.[9] This water was considered dead storage and was never released into the Delta.

2.2.2 Project Island Water Quality

Water quality from the project islands was modeled two different ways using DSM2: (1) by normal mixing in order to simulate EC, and (2) by increasing the concentration of DOC in the project reservoirs as a function of time. These two different approaches are described in detail below.

EC

For the QUAL EC simulations the reservoirs were isolated from the Delta channels as described in the previous section and flow between the surrounding channels and the project islands were regulated in DSM2 by using a direct "object-to-object" transfer. When water was diverted into the islands, this object-to-object transfer moved water from both of the siphons into or out of the reservoir. Project island diversions and releases were evenly split between the two siphons on each island.

This process allowed QUAL to automatically mix incoming EC concentrations from the nearby channels (or an adjacent non-project reservoir) with the EC already present in the reservoirs. The EC concentration of the island reservoirs only changed when water was transferred into the islands, not when water exited the islands. This process is described in greater detail in Section 4.1.

DOC

Based on work conducted by Jung (2001a), QUAL was modified for the DOC simulations such that the DOC concentration in each of the island reservoirs would increase as a function of time as described by Pandey (2001). When water was transferred into the reservoirs using the same object-to-object transfer described above, QUAL would reset the quality of the reservoir to mix with the DOC concentration of the incoming water. After this initial transfer, the DOC concentration would then increase based on Jung's growth functions (for more details see Section 3.2.2).

2.2.3 Habitat Island Configuration

In addition to modeling changes due to the operation of the project on Bacon Island and Webb Tract, changes were made in the consumptive use of Holland Tract and Bouldin Island in accordance with the plans to convert these two islands to become wetland habitats. The locations of the agricultural diversions were left unchanged for both habitat islands, but the agricultural returns on the habitat islands were moved to a single location for each island. This was done, because it was assumed that existing siphons would still be used to divert water onto the islands in order to maintain the wetland habitats, but the releases would be easier to manage

[9] DSM2 can not run if a reservoir or channel becomes completely dry. This dead storage was added for the benefit of DSM2.

through a single discharge point. The DSM2 representation of Holland Tract and Bouldin Island is shown in Figures 2.5 and 2.6.

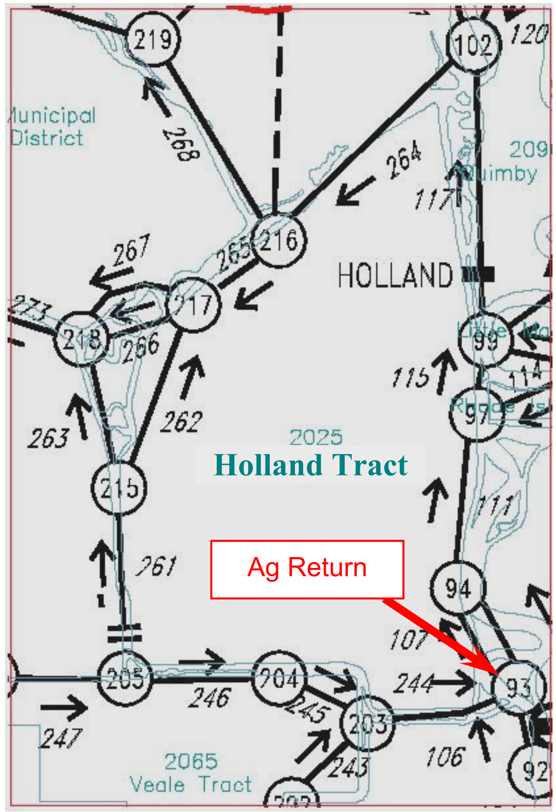

Figure 2.5: DSM2 Representation of Holland Tract.

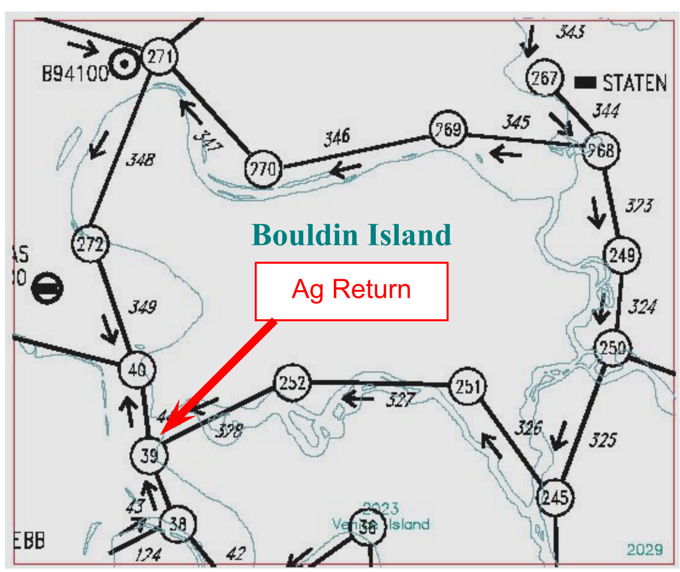

Figure 2.6: DSM2 Representation of Bouldin Island.

2.2.4 Project and Habitat Island Land Use

With changes in the land use of the project islands, the diversions and return flows for the project islands were modified using the DICU model. DICU computes the consumptive use at each node in DSM2 based on historical needs for each island or water habitat in the Delta. The diversions and return flows for each island are distributed to different nodes, such that the modeled diversions, return flows, and/or seepage at any one node frequently include the individual contributions from different islands. The diversions and return flows for the project islands were removed from all of the nodes surrounding the islands (i.e. there were no agricultural diversions or return flows associated with the project islands).

Monthly average consumptive use data taken from the Delta Wetlands EIR (see Figure 2.7) for the habitat islands were used to represent the water needs of the wetland habitats. The same monthly flow value was applied to both Holland Tract and Bouldin Island in each year of the simulation. The total diversions were divided equally among the siphons for each island, while as noted above, the return flow was discharged at a single location for each island.

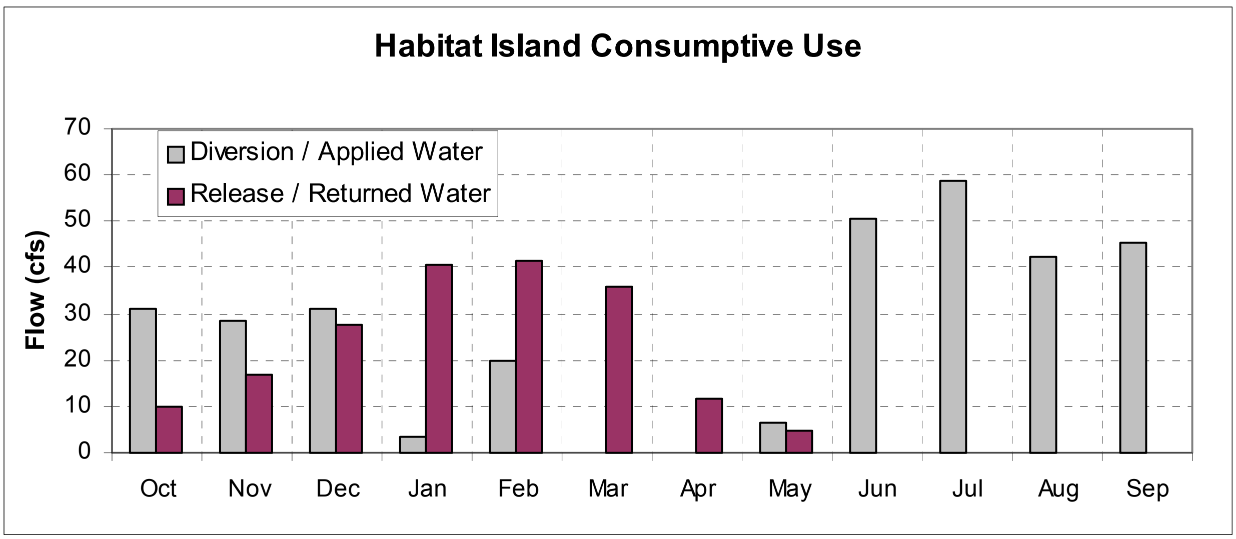

Figure 2.7: Monthly Habitat Island Consumptive Use

Even though the amount of water returning to the Delta from each habitat island changed each month (see Figure 2.7), the quality of this returned water was set to fixed concentrations as shown in Table 2.3. The DOC concentrations were based on return water quality observations taken on Holland Tract, Twitchell Island, and in similar wetland habitats (Jung, 2001b). The EC concentrations for the habitat islands are based on observations of the annual averages for each island.

Table 2.3: Habitat Island Return Water Quality Concentrations.

Habitat Island	Return EC Concentration (umhos/cm)	Return DOC Concentration (mg/l)
Bouldin Island	750	50
Holland Tract	1100	40

Since seepage in DSM2 represents the amount of water that comes from the Delta channels to the islands, it was not modified for either scenario.

3 Simulation Inputs

3.1 Hydrodynamics

3.1.1 Flow

Tributary flows, exports, and diversions were provided by CALSIM II for both the base and alternate case simulations. Similar CALSIM II studies that were used in previous DSM2 In-Delta Storage simulations are described by Easton (2001). The tributary flows include the Sacramento River, San Joaquin River, and the Yolo Bypass and one combined parameter representing the eastside flows into the Delta. Exports include the State Water Project (SWP), the Central Valley Project (CVP), Vallejo diversions, North Bay Aqueduct diversions, and Contra Costa Canal diversions from Rock Slough. Contra Costa operations on the Old River for the Los Vaqueros reservoir intake were not available for this particular CALSIM II study.

The CALSIM II studies assumed a 2020 level of development for the Delta Island Consumptive Use (DICU). The DICU model was run to create two different sets of agricultural irrigation and drainage representations of the Delta for 2020 water demands. The base case consumptive use represented only a factoring upward of the historical Delta water demands to meet the 2020 level of use. The changes to the alternative consumptive use patterns accounted for the change in land use of the project islands and habitat islands. These changes were first made to the historical consumptive use patterns, and then the altered consumptive use data were adjusted to the 2020 level of demand. It is important to note that when the DICU model adjusts the historical consumptive use levels, that it increases all of the Delta flows upward or downward based on an estimate of total Delta consumptive use for the new demand level. The DICU model can not change the level of future demand, hence the base and alternative 2020 DICU results have the same total Delta consumptive use value. However, the changes made to the land use of the project and habitat islands mean that the amount of diversions and returns from all of the Delta islands are slightly different between the two consumptive use patterns.

3.1.2 Stage

A new planning tide developed by Ateljevich (2001b) was applied at the Martinez downstream boundary. This 15-minute tide incorporates historical data and includes two primary components:

- An astronomical tide that includes Spring-Neap variation and accurate harmonic components; and

- A residual tide with long-period fluctuations due to barometric changes and other nonlinear interactions.

3.1.3 Gates

Delta Cross Channel

Unlike previous planning studies where monthly operations were used for the Delta Cross Channel (DCC) position, CALSIM II provided daily operations of the DCC. The DCC was opened and closed by CALSIM II in accordance with State Water Resources Control Board (SWRCB) D-1641 standards.[10]

South Delta Permanent Gates

The proposed future operation of the three South Delta agricultural permanent gates (Old River at Tracy, Middle River, and Grant Line Canal) and the fish protection barrier at Old River at Head was used in this study. When operating, the gates only allowed flow in the upstream direction. Each structure may be either installed or removed during the 13 planning periods, see Figure 3.1 below. Each month represents one planning period, with the exception of April, which is divided into two planning periods. This was done so the gates could be installed in the middle of the month, per the proposed future operation of the gates.

Barrier	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Old River @ Head												
Old River @ Tracy												
Middle River												
Grant Line Canal												

Figure 3.1: Schedule of Permanent Barrier Operations.

Other Gates

The Suisun Marsh Salinity Control Gate was operated October through May of each year. The Clifton Court Forebay Gates allowed water into the Forebay from the Old River when a difference in stage occurred between the river and the Forebay. This was referred to as a priority four operation in previous DSM2 planning studies.[11] Water was not allowed to leave the Forebay.

3.2 Quality

Water quality inputs were applied both at the external boundaries and at the Delta interior locations through use of the Delta Island Consumptive Use (DICU) model. Furthermore, QUAL was modified to account for increases in DOC stored in the project reservoirs based on research conducted by Jung (2001a). The sources and nature of these data are discussed below.

[10] The SWRCB D-1641 standards for the DCC stipulate that the DCC must be closed when: (1) flow in the Sacramento River is greater than 23,000 cfs, (2) for 45 days in Nov. - Jan., and (3) Feb. - May.

[11] There are four different typical schedules of operation of the Clifton Court Forebay Gates that were used in previous DSM2 planning studies. These schedules were designed to optimize the amount of water entering the Forebay, while minimizing the impact on South Delta stage. The work to create these different priority operations in DSM2 with the new historical-based tide used at Martinez is not yet completed.

3.2.1 EC

As discussed above in Section 2.1, Martinez EC was generated using Net Delta Outflow (calculated from the CALSIM II results) and an updated G-model, based on work done by Ateljevich (2001a).

CALSIM II provided monthly EC values for the San Joaquin River. Using the daily San Joaquin River flow and the monthly EC values, daily EC values were derived.

The EC concentration at the remaining tributary boundaries, the Sacramento River, the Yolo Bypass, and the eastside streams, was fixed at 200 umhos/cm.

Standard DICU data developed from the DICU model were used to represent the quality of water draining off the Delta islands. For the base case all of the standard DICU node locations and EC concentrations were used. For the alternative case the standard DICU node EC concentrations were used, but as discussed above in Section 2.2.4, the diversions and return flows were altered.

3.2.2 DOC

Jung (2001a) reports that flooding Delta islands may result in increases in the DOC, due in part to peat soil DOC releases. A series of experiments were conducted to find the rate of DOC growth on Delta islands, and then a conceptual model was created to simulate this DOC growth. QUAL was modified to account for increases in DOC due to storage, using Equation 1 (see Jung 2001a).

$$DOC(t) = \frac{A}{1 + Be^{-kt}} \qquad \text{[Eqn. 1]}$$

where

A = maximum island DOC concentration (mg/l),
B = initial DOC concentration of diversion into island,
k = growth rate of DOC ($days^{-1}$), and
t = time relative to initial diversion into island (days).

Two different bookend simulations were run, to represent low and high ranges of DOC released from the islands. A summary of the coefficients used in Equation 1 and the range of DOC releases as modeled in QUAL is shown in Table 3.1. The initial DOC concentration was calculated within QUAL and takes the depth of the reservoir into account. This term is hardwired into QUAL. For most of the releases the DOC coming off the islands was less than the maximum values listed below.

Table 3.1: QUAL DOC Bookends.

Bookend	A (mg/l)	k ($days^{-1}$)	Range of Released DOC
Low	70	0.022	6 - 10 mg/l
High	215	0.022	13 - 22 mg/l

Another area that would affect DOC growth in the project islands is bioproductivity. This was not considered in these simulations.

The DOC concentrations for the San Joaquin River, Sacramento River, and eastside streams were developed based on MWQI observations taken from 1987 through 1998 (Suits, 2001a). The summer DOC concentrations were based on monthly averages of the June through October observations. The winter DOC concentrations were generated using relationships relating DOC to flow. These relations were then used to create DOC concentrations for the three tributary boundary locations for the entire 16-year simulation period. The Sacramento River DOC concentrations were also applied to the Yolo Bypass flows. The range of the DOC concentrations at the rim boundaries is summarized in Table 3.2 below.

Table 3.2: Range of Tributary Boundary DOC (mg/l) Concentrations.

	San Joaquin	Sacramento	Eastside Streams
DOC Range	2.40 - 11.40	1.81 - 5.65	1.66 - 3.95

DICU data developed as part of the DWR MWQI studies were used to represent the DOC (mg/l) draining off the Delta islands (see Jung, 2000). Three different ranges of DOC returns were used to represent return water DOC concentrations in the Delta. Figure 3.2 represents the DOC values used in QUAL. In DSM2 each island in the Delta was assigned either the high, middle, or low range DOC release concentrations. The high range DOC is associated with DOC releases from the Delta islands that peak out above 30 mg/l. The islands with high range DOC releases were located in the central Delta, and include the islands neighboring both the project and habitat islands. The low range DOC is used for islands that were found to have low DOC releases.

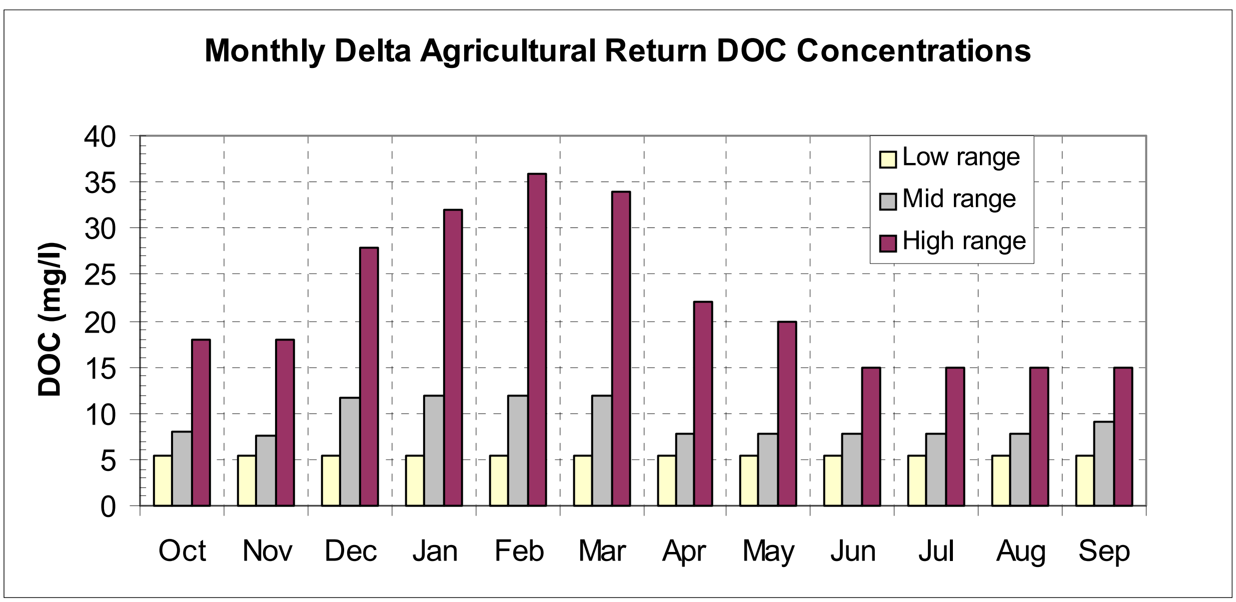

Figure 3.2: Monthly Averaged DOC Concentrations from Agricultural Returns.

3.3 Initial Conditions

DSM2 planning studies cover a 16-year period from Oct. 1975 to Sep. 1991. Unlike HYDRO, QUAL requires a much longer start-up period. In the case of planning studies, no assumption is made about the initial water quality conditions in the Delta; thus an extra year is run in order to simulate the mixing of the Delta. This is called a cold start routine. Both HYDRO and QUAL are run for this extra year, but the results are disregarded during this cold start period.

4 Results

This report discusses five water quality constituents, chloride, dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UVA), total trihalomethane (TTHM), and bromate. The long-term impacts on chloride and DOC are also discussed. QUAL was used to simulate EC and DOC, and then these constituents were used to calculate chloride, UVA, TTHM and bromate formation potentials.

Modeled water quality at the following locations are shown below in Figure 4.1 for the entire planning period (1975 - 1991): Contra Costa's Rock Slough intake near the Old River, Contra Costa's Los Vaqueros intake on the Old River, the SWP and CVP intakes at Banks and Tracy Pumping Plants. These DSM2 output locations correspond with field sampling locations. This report focuses only on water quality at these locations.

For the alternative simulation, the percentage of the time of year water was diverted to and later released from the project islands for the entire study period is shown in Figures 4.2 and 4.3. Generally the islands were filled in the winter months (Nov., Dec., Jan., Feb. and Mar.) and emptied in the summer months (Jun. and Jul.). Webb Tract is filled and emptied after Bacon Island has reached capacity; hence 100% of its releases are in July. During the summer months, CALSIM II frequently diverted small amounts of water to the project islands to account for evaporation losses.

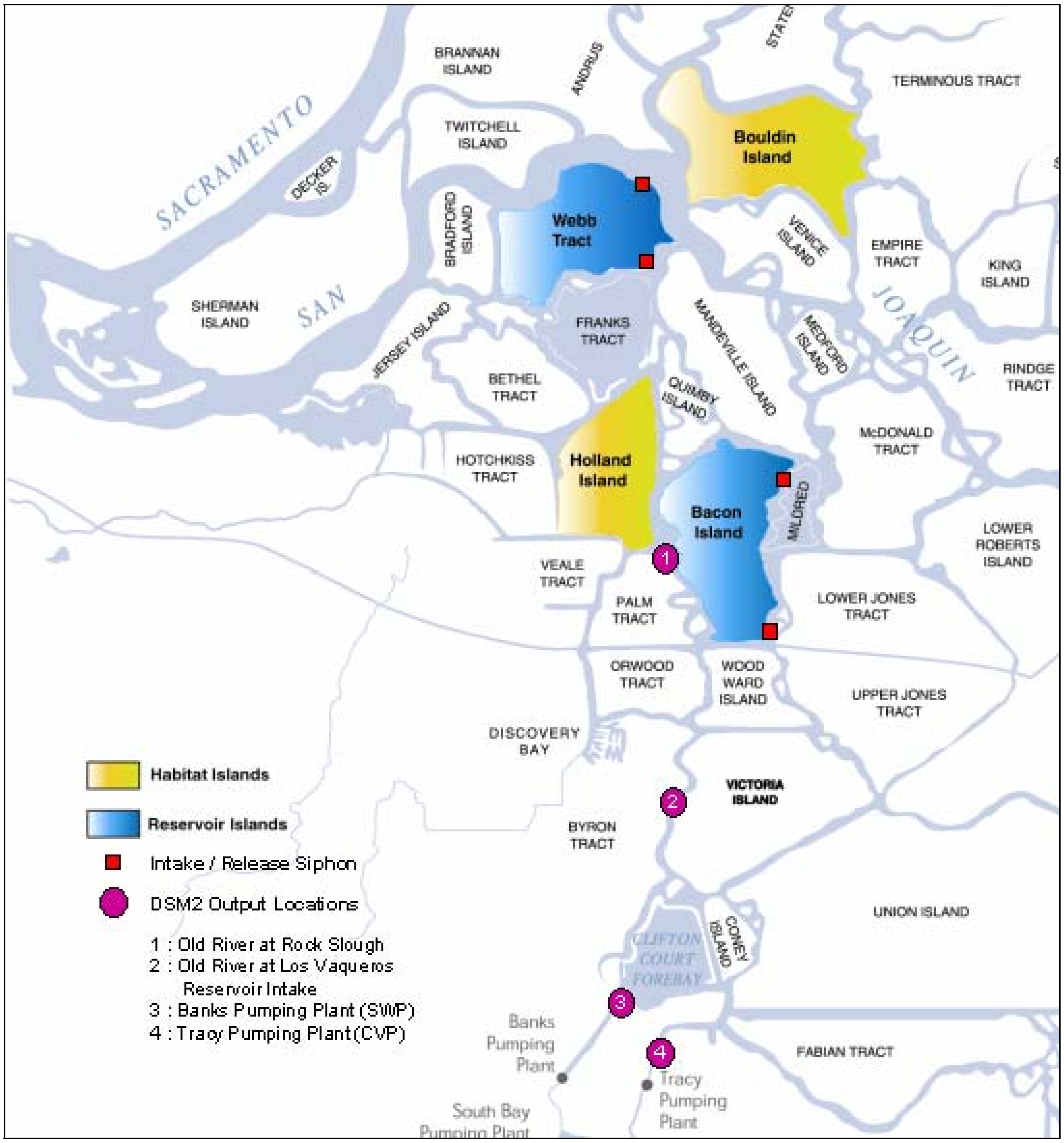

Figure 4.1: Location of In-Delta Storage Project Islands and DSM2 Output Locations.

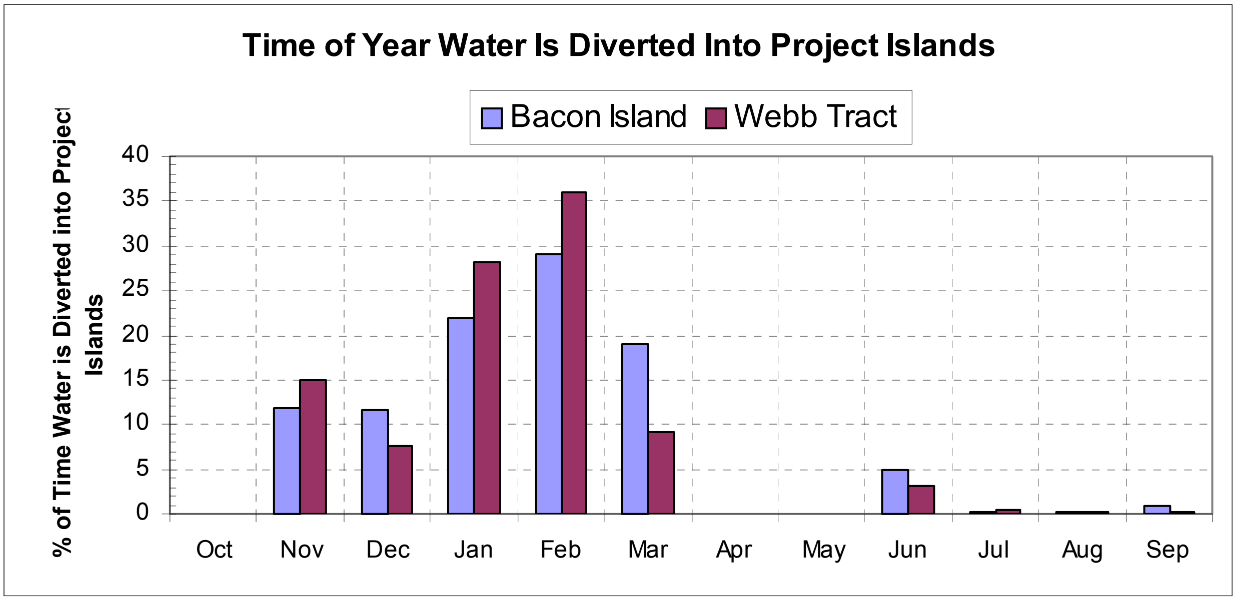

Figure 4.2: Time of Year Water is Diverted to Project Islands.

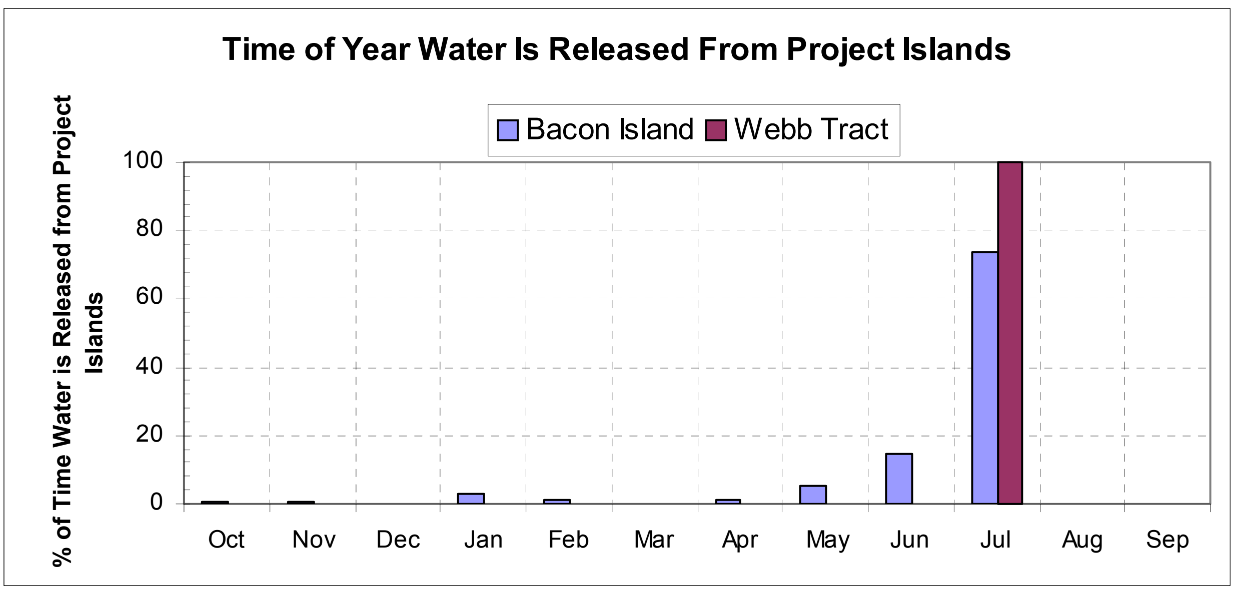

Figure 4.3: Time of Year Water is Released from Project Islands.

The diversions and releases compared to the storage of both Bacon Island and Webb Tract as modeled in HYDRO are shown in Figures 4.4 and 4.5. Though the maximum design storage for Bacon Island and Webb Tract were listed as 120 and 118 TAF respectively, the CALSIM operations never reached these two capacities in DSM2. Figures 4.4 and 4.5 show the maximum modeled storage to be 115 and 102 TAF for Bacon Island and Webb Tract. The small loss of storage between each major diversion and release is due to evaporation, which was provided by CALSIM.

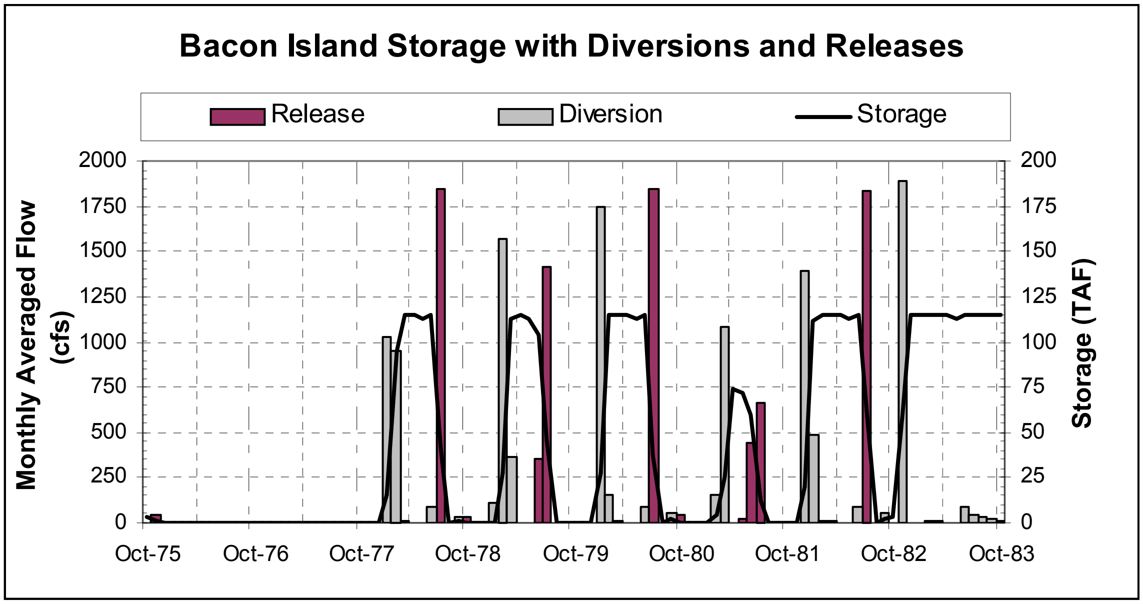

Figure 4.4a: Bacon Island Storage with Diversions and Releases 1975 - 1983.

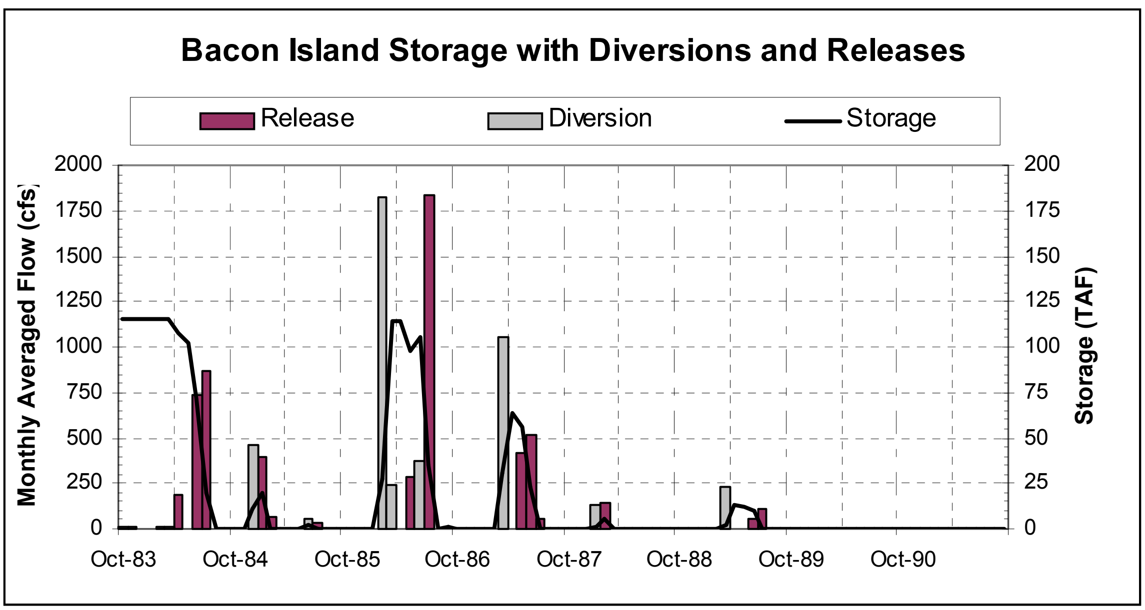

Figure 4.4b: Bacon Island Storage with Diversions and Releases 1983 - 1991.

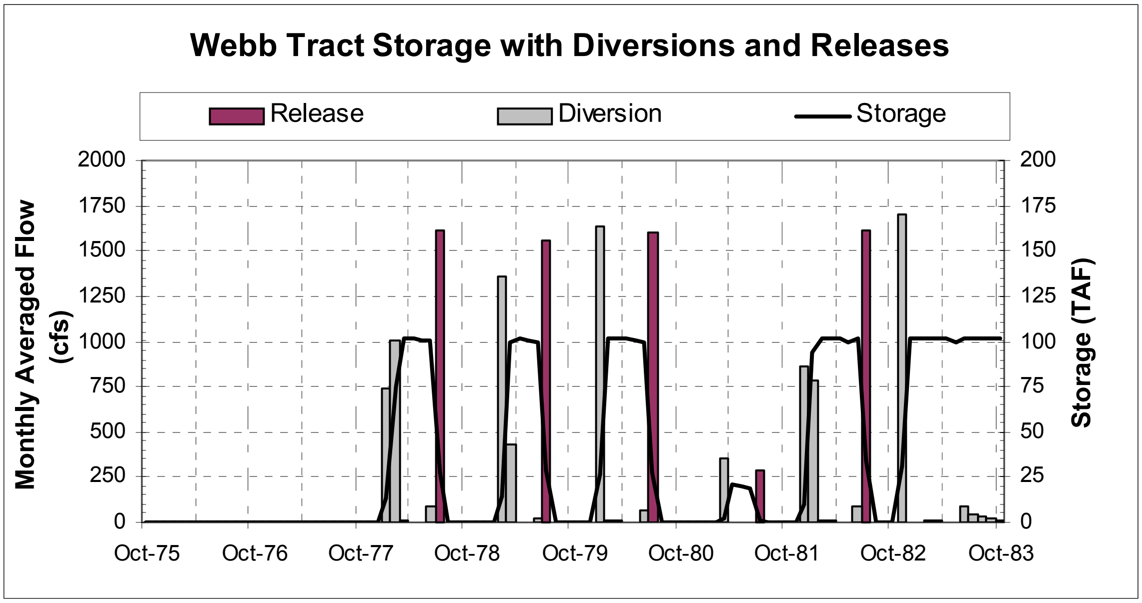

Figure 4.5a: Webb Tract Storage with Diversions and Releases 1975 - 1983.

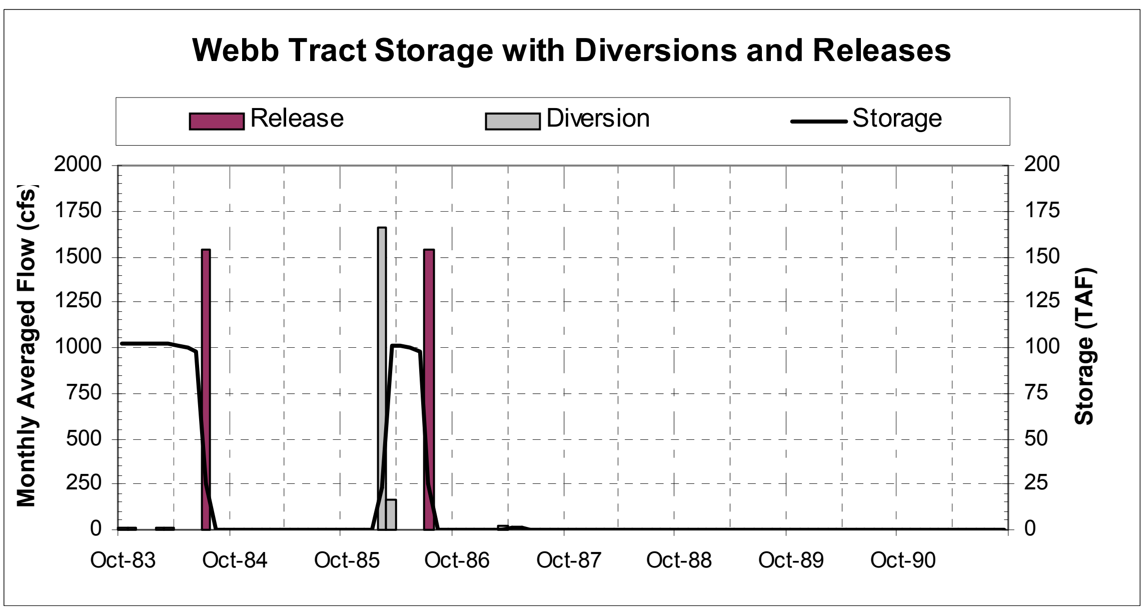

Figure 4.5b: Webb Tract Storage with Diversions and Releases 1983 - 1991.

4.1 Chloride

As described above in Table 2.2.1 (see Section 2.2), two reservoirs were created in DSM2 to simulate chloride (modeled as EC in QUAL) coming from the two project islands: Bacon Island and Webb Tract. These reservoirs were connected to the Delta in DSM2 by using object-to-object transfers. This technique controlled when water would be added to or removed from the reservoirs.

Since the chloride concentration of the reservoir islands is a function of the chloride around the intakes and the current chloride concentration in each island reservoir, QUAL was able to store the water and account for changes in water quality due to mixing, as shown in Equation 2 where concentrations are represented by C and volumes are represented by V. The only time chloride concentration in the islands would change was when water was diverted into the islands, which can be seen in Figures 4.6 and 4.7.

$$C_{new} = \frac{C_{\inf lows} V_{\inf lows} + C_{island} V_{island}}{V_{\inf lows} + V_{island}} \qquad \text{[Eqn. 2]}$$

If the EC concentration of the water at the intakes were lower than the EC levels inside the island reservoir, then the inflows would reduce the island EC concentration. If the EC concentration of the water at the intakes were higher than the EC levels inside the island, then the inflows would increase the island EC concentration. Discharges from the islands did not change the water quality of the reservoirs and had little impact on the EC concentration in the Delta itself.

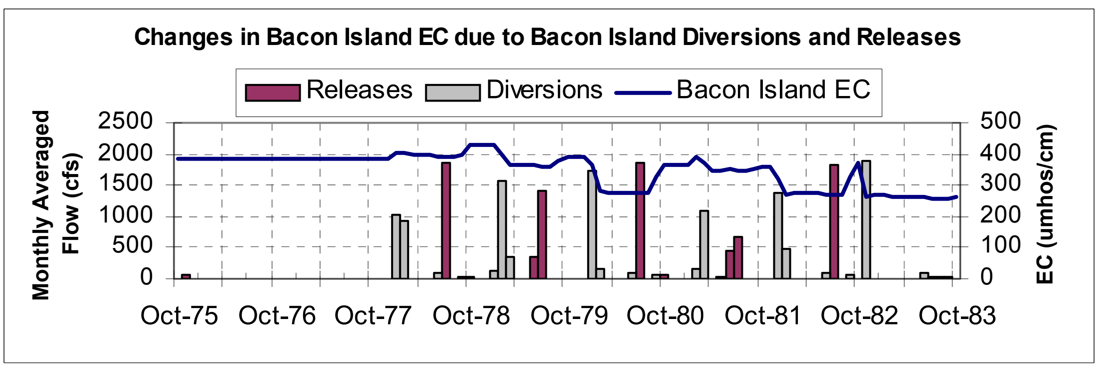

Figure 4.6a: Changes in Bacon Island EC due to Project Diversions and Releases 1976-1983.

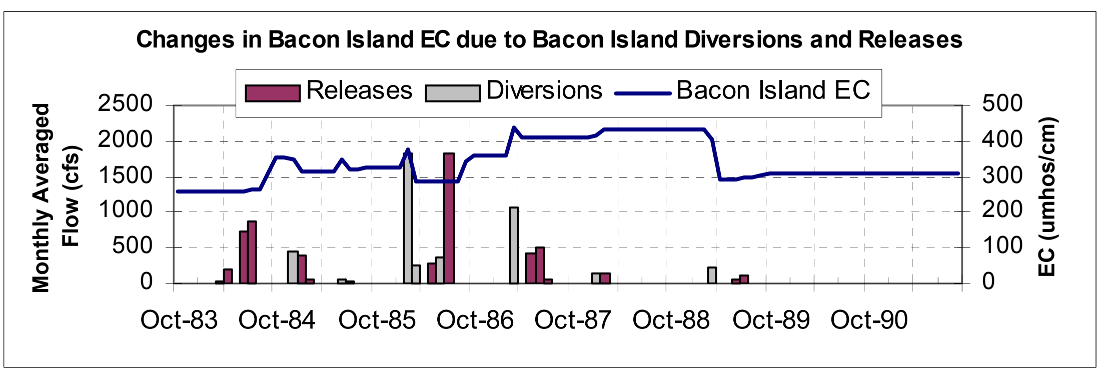

Figure 4.6b: Changes in Bacon Island EC due to Project Diversions and Releases 1983-1991.

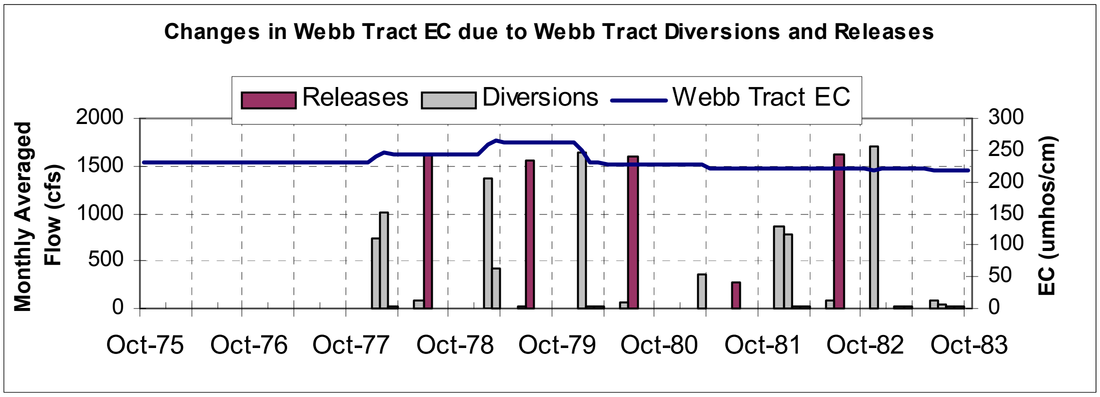

Figure 4.7a: Changes in Webb Tract EC due to Project Diversions and Releases 1976-1983.

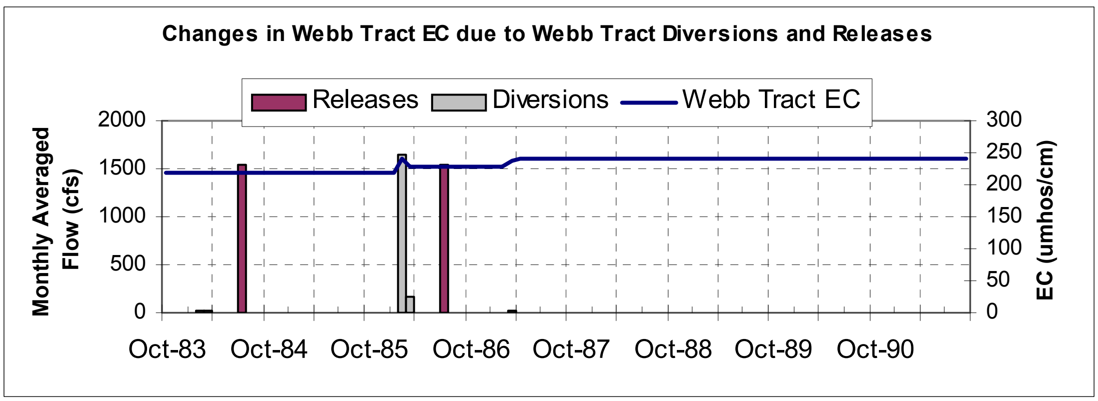

Figure 4.7b: Changes in Webb Tract EC due to Project Diversions and Releases 1983-1991.

EC (umhos/cm) was converted to chloride (mg/l) using the following relationships (Suits, 2001b):

$$Chloride_{Contra\,Costa\,Pumping\,Plant\,\#1} = \frac{EC_{Old\,River\,at\,Rock\,Slough} - 89.6}{3.73} \quad \text{[Eqn. 3]}$$

$$Chloride = \frac{EC - 160.6}{3.66} \quad \text{[Eqn. 4]}$$

Equation 3 is used to convert modeled EC to chloride concentration for Contra Costa Water District's Rock Slough diversion location (Contra Costa Pumping Plant #1). Equation 4 is used to convert modeled EC to chloride at all of the other intake locations. The relationships developed by Suits were based on field observations. However, during a few periods QUAL's EC concentrations were so low that using these field conversions resulted in chloride concentrations that were too low. A minimum chloride concentration of 10 mg/l was assumed during these periods.

The impacts of the project releases are compared to the base case scenario in Figures 4.8 - 4.19. Figures 4.8, 4.11, 4.14, and 4.17 illustrate the time series of monthly averaged chloride concentration at the four intake locations for the entire 16-year study period. The Water Quality

Management Plan (WQMP, 2000) 225 mg/l chloride constraint is shown on these figures. The WQMP limited this constraint to be 90% of existing D-1641 salinity standards (Hutton, 2001).

The 225 mg/l WQMP chloride constraint was exceeded at the Old River at Rock Slough and Tracy (CVP) intake locations for both the base and alternative studies in 1977. The WQMP constraint was not exceeded in either scenario at the Los Vaqueros or Banks (SWP) intake locations. The maximum monthly averaged chloride for the four intake locations is listed in Table 4.1. All of these maximums occurred in 1977. The maximum monthly averaged chloride concentration was larger in the alternative than in the base study at all four locations.

Table 4.1: Maximum Monthly Averaged Cl (mg/l).

Location	*Base*	*Alternative*
Old River at Rock Slough	235	243
Old River at Los Vaqueros Intake	191	197
Banks Pumping Plant (SWP)	222	223
Tracy Pumping Plant (CVP)	246	247

The WQMP stipulated that the maximum increase in chloride concentration due to operation of the project is 10 mg/l when the base case chloride concentration is less than the 225 mg/l constraint, otherwise no increase is allowed (Hutton, 2001). Time series of the difference between the alternative and base case chloride results for the four intake locations and change in chloride concentration constraint for the 16-year period are illustrated in Figures 4.9, 4.12, 4.15, and 4.18. The maximum increase in monthly averaged chloride when this incremental 10 mg/l constraint applies is listed in Table 4.2. The WQMP incremental chloride constraint is exceeded at all four urban intake locations during the 16-year simulation.

Table 4.2: Maximum Increase in Monthly Averaged Cl (mg/l) When Base Chloride is Less Than 225 mg/l.

Location	*Alt. - Base*
Old River at Rock Slough	32
Old River at Los Vaqueros Intake	25
Banks Pumping Plant (SWP)	18
Tracy Pumping Plant (CVP)	18

The Cumulative Distribution Function (cdf) for the change (measured as alternative - base case) in chloride concentration at each location is shown in Figures 4.10, 4.13, 4.16, and 4.19. These cdfs were calculated based on a frequency histogram of the difference in chloride concentration (alternative - base) for every month of the entire 16-year simulation. Each cdf curve represents the amount of time that the chloride concentration is equal to or less than a corresponding chloride level. These figures illustrate that over the study period that the overall changes in chloride tended to be between -20 and 20 mg/l. These plots are useful in measuring the impact of the In-Delta Storage project operations on the four urban intake locations.

A summary of the percent of time that this increase in salinity (alternative - base) exceeded the WQMP constraint is shown below in Table 4.3. The largest increase in chloride was at Old

River at Rock Slough, where the WQMP chloride constraint was exceeded approximately 5.7% of the time.

Table 4.3: Percent of time that the change in Cl is larger than 10 mg/l.

Location	***% Exceedance***
Old River at Rock Slough	5.7
Old River at Los Vaqueros Intake	5.2
Banks Pumping Plant (SWP)	3.6
Tracy Pumping Plant (CVP)	3.6

The number of months that the two WQMP Cl constraints were exceeded for both the base and alternative simulations is shown below in Table 4.4. The values in Table 4.4 were taken from the entire 16-year (192 month) period, however the project only diverted or released water during 75 of these months.[12] The last column in Table 4.4 shows the total number of months the WQMP Cl constraints were violated. If the 225 mg/l constraint was violated in the alternative, but not in the base case during a month that when the 10 mg/l change in Cl constraint was also exceeded, that month was not double counted.

Table 4.4: Number of Months of Exceedance of the WQMP Cl Standards.

	225 mg/l Cl Constraint		**10 mg/l Change in Cl Constraint**	**Total Number of Months in Violation**
Location	***Base***	***Alt***	***Alt - Base***	***Alt - Base***
Old River at Rock Slough	3	3	11	11
Old River at Los Vaqueros Intake	0	0	10	10
Banks Pumping Plant (SWP)	0	0	7	7
Tracy Pumping Plant (CVP)	1	1	7	7

The number of months in which the 225 mg/l Cl standard was violated was the same in both the base and alternative simulations. The largest number of total WQMP violations was at Rock Slough.

[12] Out of the 192 months simulated, water was diverted into or released from the project islands during 75 months. These diversions include the smaller flows that were taken by the project in order to account for evaporation losses. Many of these smaller diversions were less than 25 cfs, which is significantly smaller than many of the Delta island consumptive use diversions and return flows.

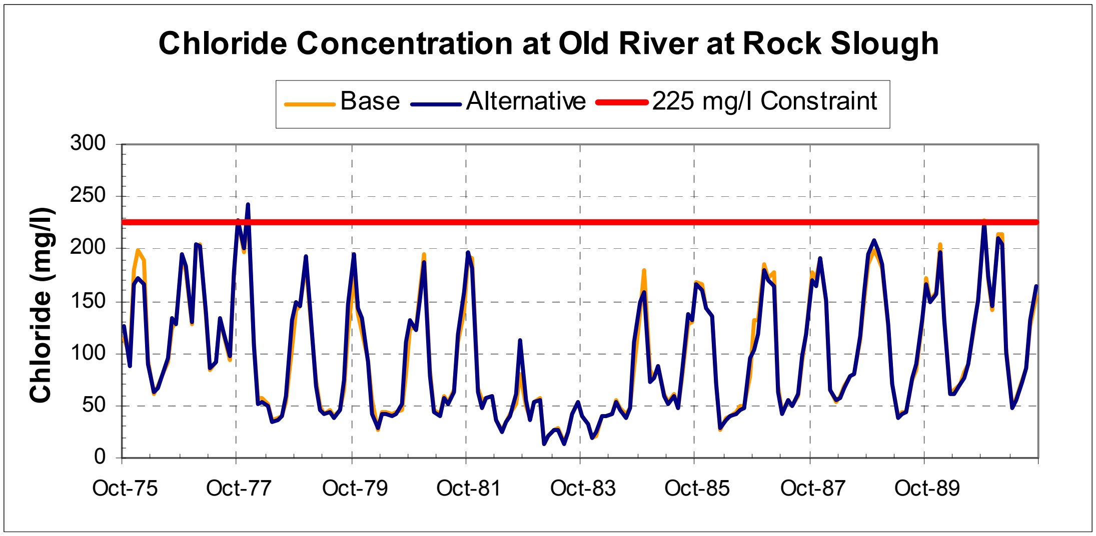

Figure 4.8: Chloride Concentration at Old River at Rock Slough.

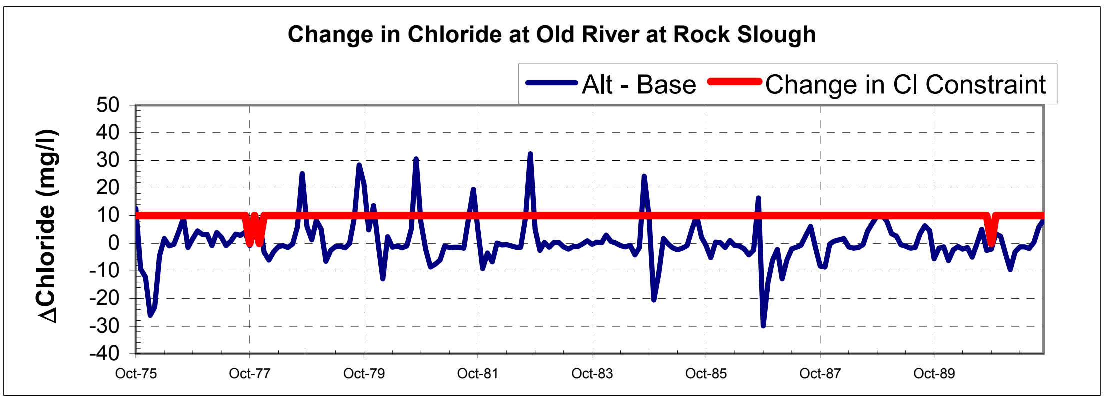

Figure 4.9: Change in Chloride at Old River at Rock Slough.

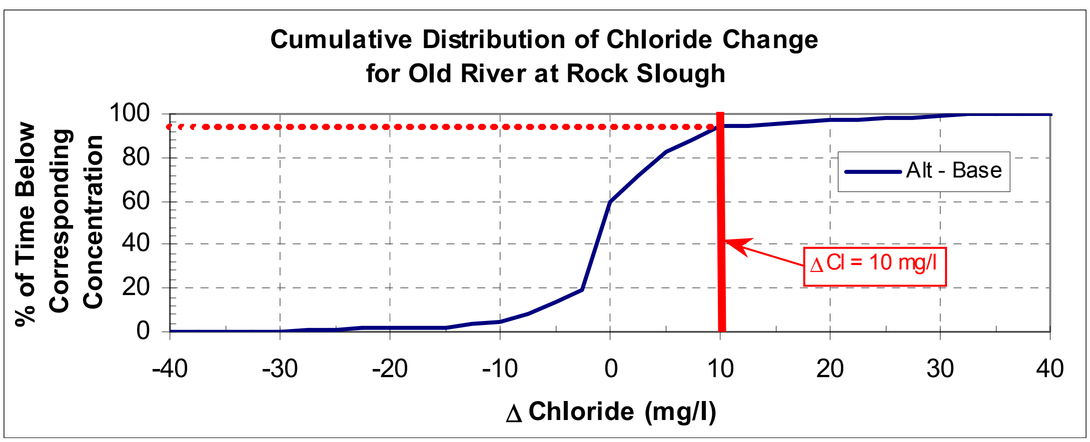

Figure 4.10: Cumulative Distribution of Chloride Change at Old River at Rock Slough.

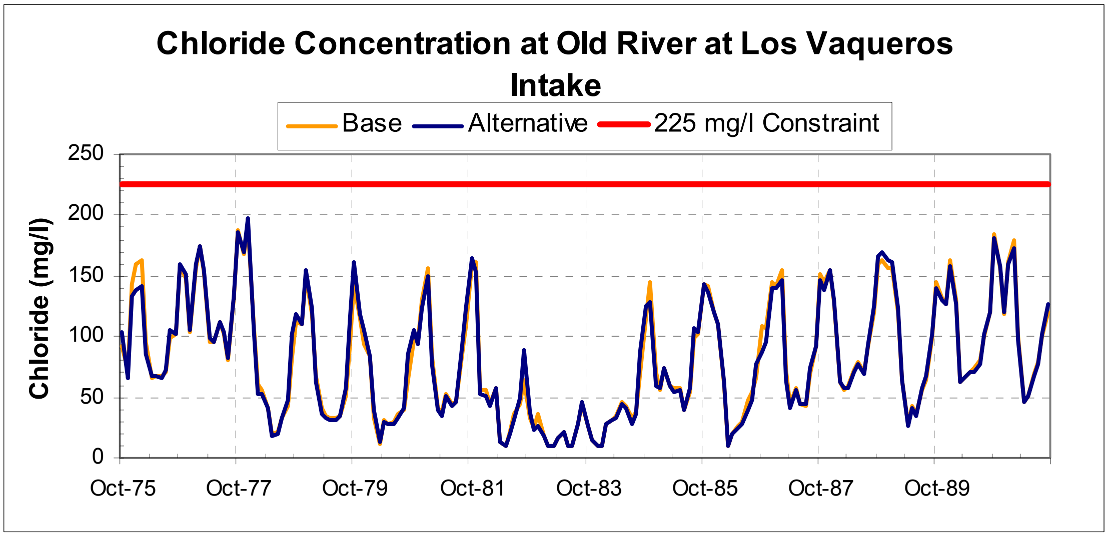

Figure 4.11: Chloride Concentration at Old River at Los Vaqueros Intake.

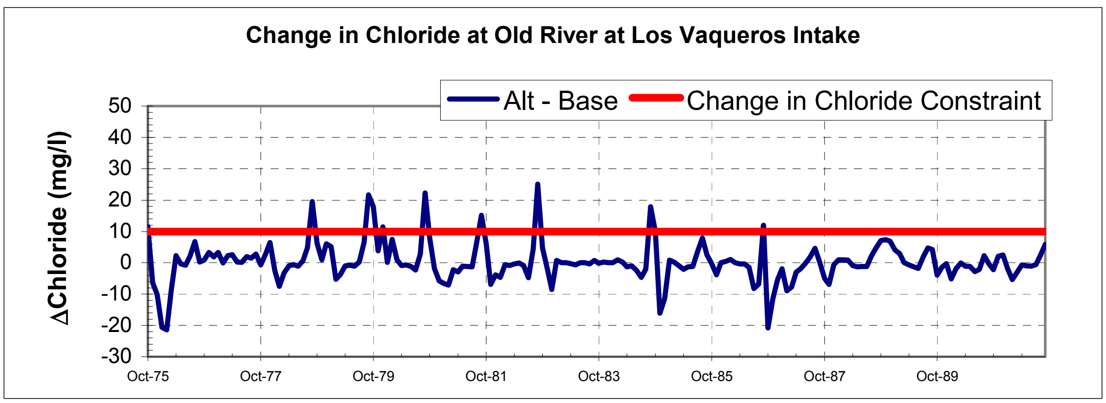

Figure 4.12: Change in Chloride at Old River at Los Vaqueros Intake.

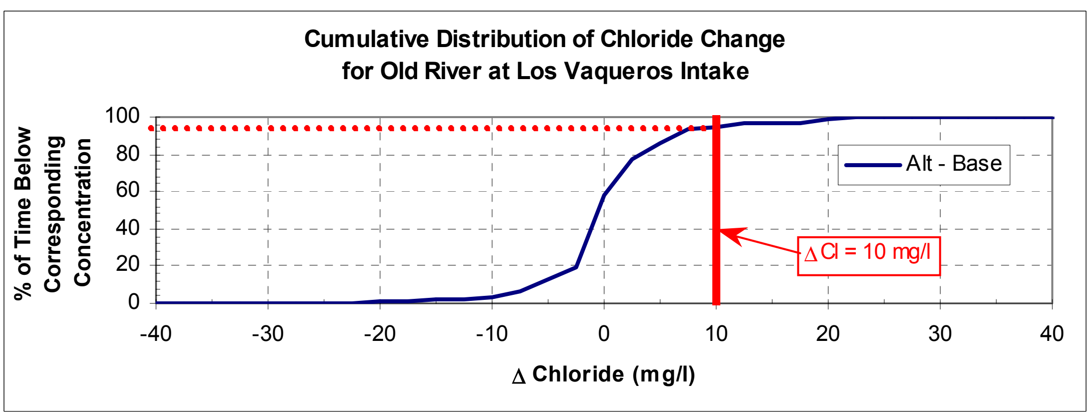

Figure 4.13: Cumulative Distribution of Chloride Change at Old River at Los Vaqueros Intake.

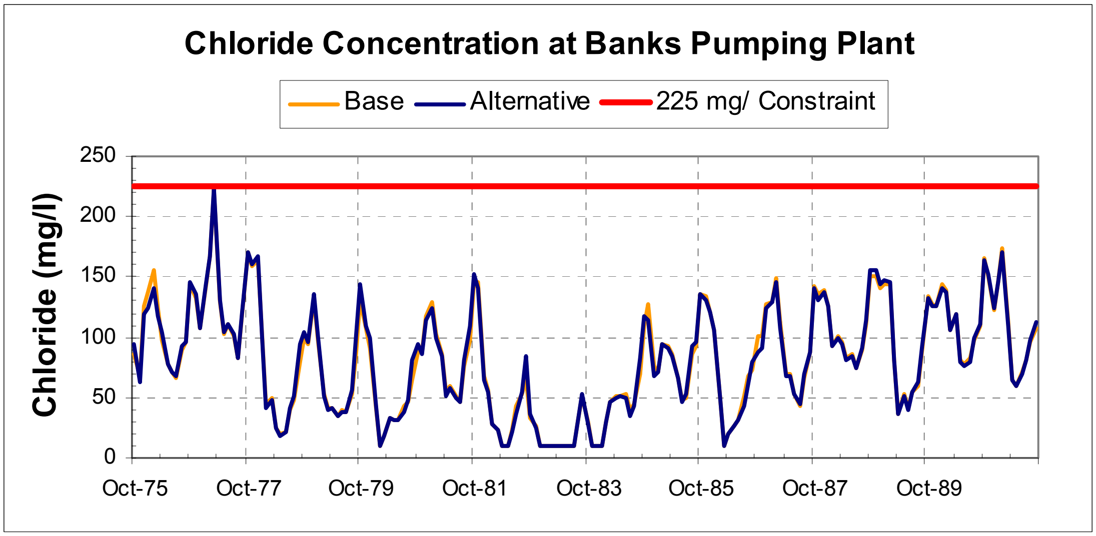

Figure 4.14: Chloride Concentration at Banks Pumping Plant.

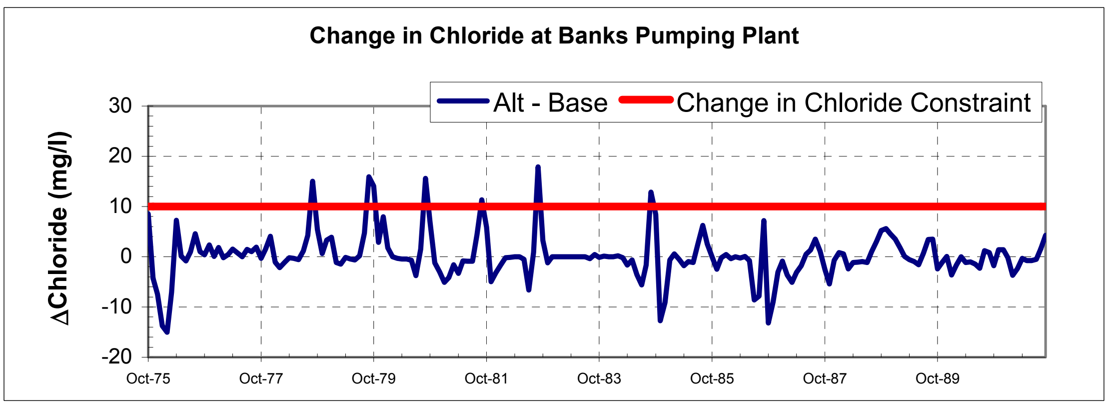

Figure 4.15: Change in Chloride at Banks Pumping Plant.

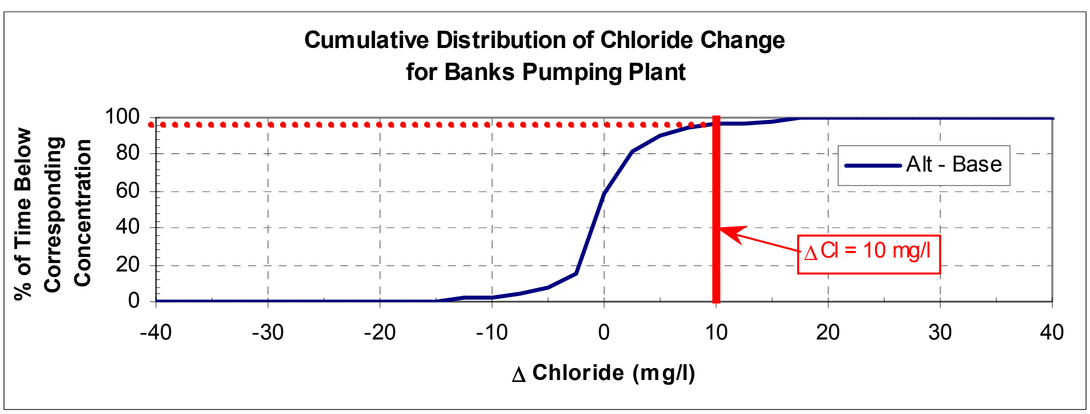

Figure 4.16: Cumulative Distribution of Chloride Change at Banks Pumping Plant.

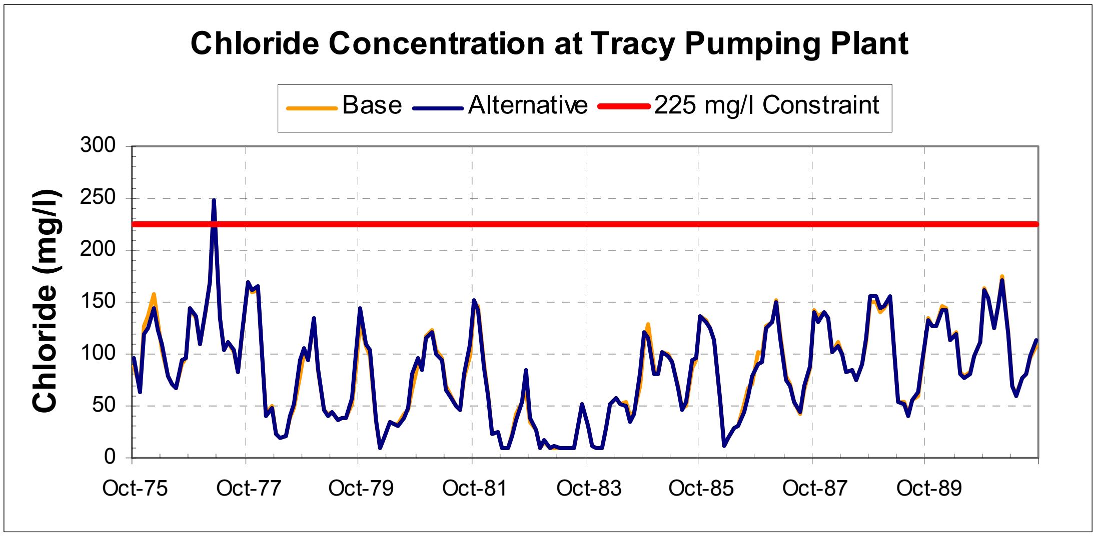

Figure 4.17: Chloride Concentration at Tracy Pumping Plant.

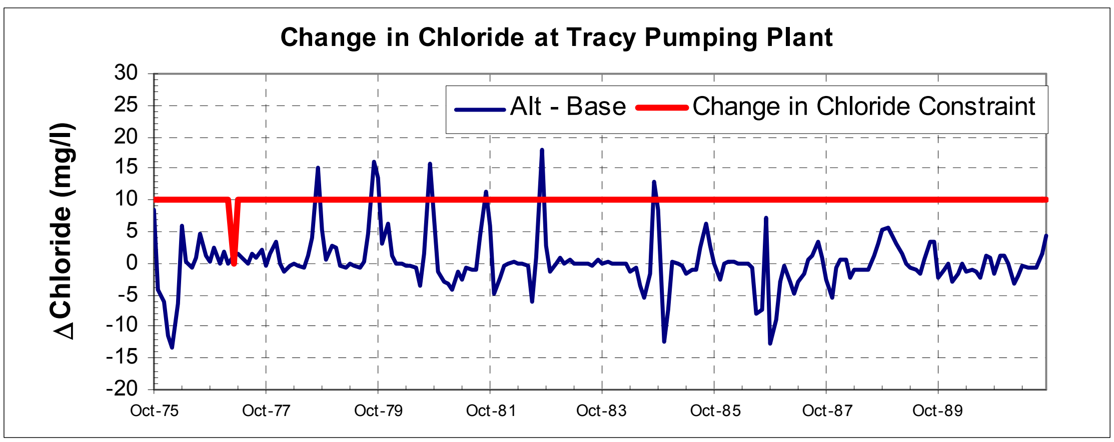

Figure 4.18: Change in Chloride at Tracy Pumping Plant.

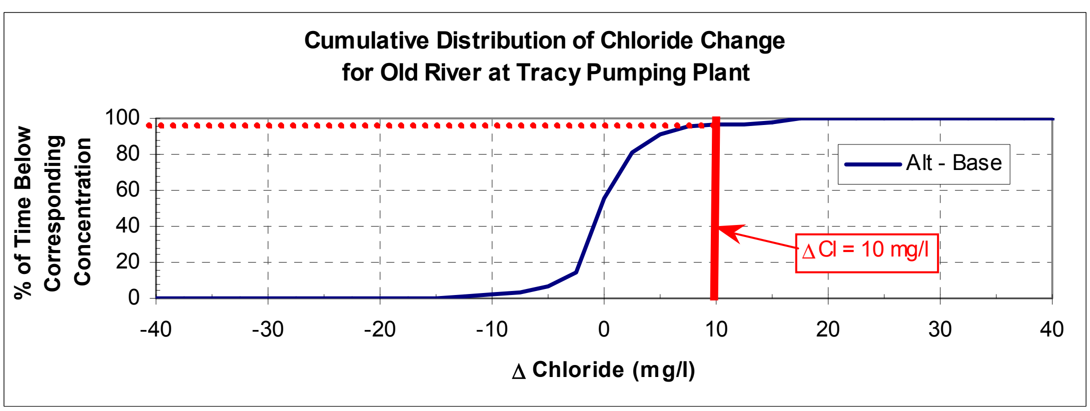

Figure 4.19: Cumulative Distribution of Chloride Change at Tracy Pumping Plant.

4.2 Long-Term Chloride

Long-term increases due to the operation of the project were calculated as the 3-year running average of monthly average chloride mass loading (see Hutton, 2001). Time series plots of the long-term monthly averaged chloride mass loading (expressed in 1000 metric tons / month) at Old River at Rock Slough and the State Water Project and the Central Valley Project intakes are shown in Figures 4.20, 4.23, and 4.26.[13] The long-term impact of the project operations was calculated using Equation 5.

$$\%Chloride_{Increase\,w/\,Project} = \frac{Chloride_{w/\,Project} - Chloride_{w/\,o\,project}}{Chloride_{w/\,o\,project}} \times 100\% \qquad \text{[Eqn. 5]}$$

The WQMP limits the long-term chloride mass loading increases at the intake locations due to the project operation to 5%. This 5% limit is shown on the time series plots (Figures 4.21, 4.24, and 4.27) of the long-term percent increase of chloride mass loading. The maximum percent increase in the long-term monthly averaged chloride mass loading is shown in Table 4.5. The alternative simulation exceeded the WQMP 5% increase constraint at Old River at Rock Slough and the Banks Pumping Plant, but the operation of the project only met the 5% increase constraint at the Tracy Pumping Plant.

Table 4.5: Maximum Percent Increase in Long-Term Monthly Averaged Chloride Mass Loading.

Location	*Percent Increase*
Old River at Rock Slough	6.6
Banks Pumping Plant (SWP)	6.5
Tracy Pumping Plant (CVP)	5.0

Frequency histograms of the percent increase in long-term chloride mass loading for the entire simulation period were used to create cumulative distribution functions (cdfs) to represent the long-term impact of the project operations. These cdfs are shown in Figures 4.22, 4.25, and 4.28. The WQMP maximum 5% increase in long-term chloride mass loading constraint is shown on each figure. The percent of the time that each scenario was equal to or below the WQMP maximum 5% increase constraint is listed in Table 4.6.

[13] Normally Contra Costa Water District (CCWD) diversions are divided between the Rock Slough and Los Vaqueros Reservoir intakes. Long-term chloride mass loading was not calculated for Old River at Los Vaqueros Reservoir intake because CALSIM II did not separate the CCWD diversions. Similarly, the mass loading calculated for Rock Slough is based on the assumption that 100% of CCWD's diversions would be taken at the Rock Slough location.

Table 4.6: Percent Time that the Percent Increase of Long-Term Chloride Mass Loading Exceeds the WQMP Maximum 5% Increase Constraint.

Location	***% Exceedance***
Old River at Rock Slough	9
Banks Pumping Plant (SWP)	5
Tracy Pumping Plant (CVP)	0

The number of months out of the 156 months that the long-term chloride mass loading increase exceeds the WQMP 5% increase constraint is shown below in Table 4.7.[14] Old River at Rock Slough experienced the largest number of violations (14 months) of the constraint.

Table 4.7: Number of Months the Long-Term Chloride Mass Loading Increase Exceeds the WQMP 5% Increase Constraint.

Location	**5% Increase Constraint**
Old River at Rock Slough	14
Banks Pumping Plant (SWP)	8
Tracy Pumping Plant (CVP)	0

[14] Instead of 192 months, the long-term mass loading calculations used the first 36 months to calculate the running average, thus long-term violations come from a sample of only 156 months.

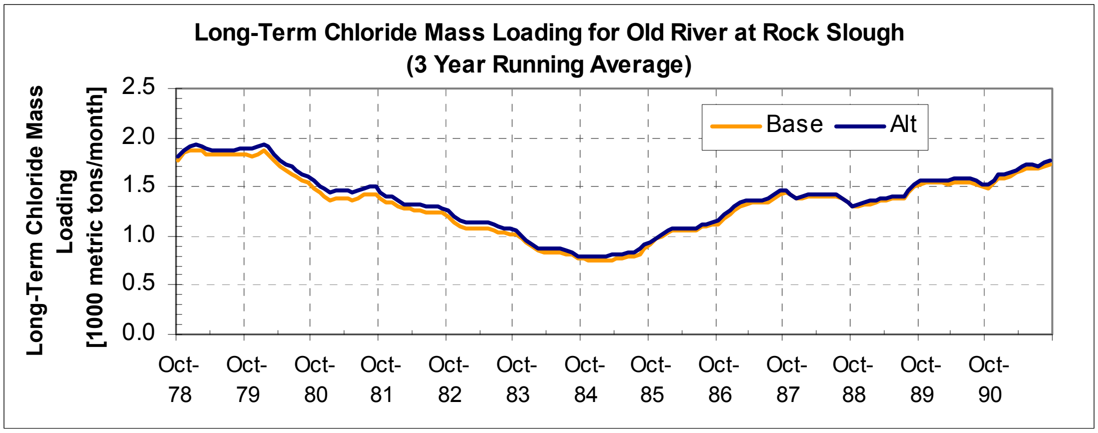

Figure 4.20: Long-Term Chloride Mass Loading for Old River at Rock Slough.

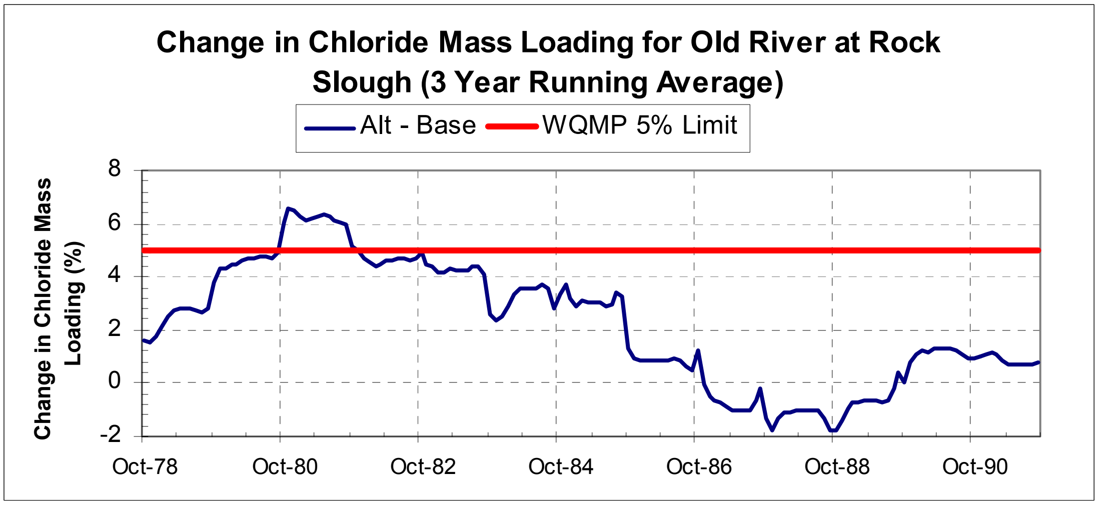

Figure 4.21: Change in Long-Term Chloride Mass Loading for Old River at Rock Slough.

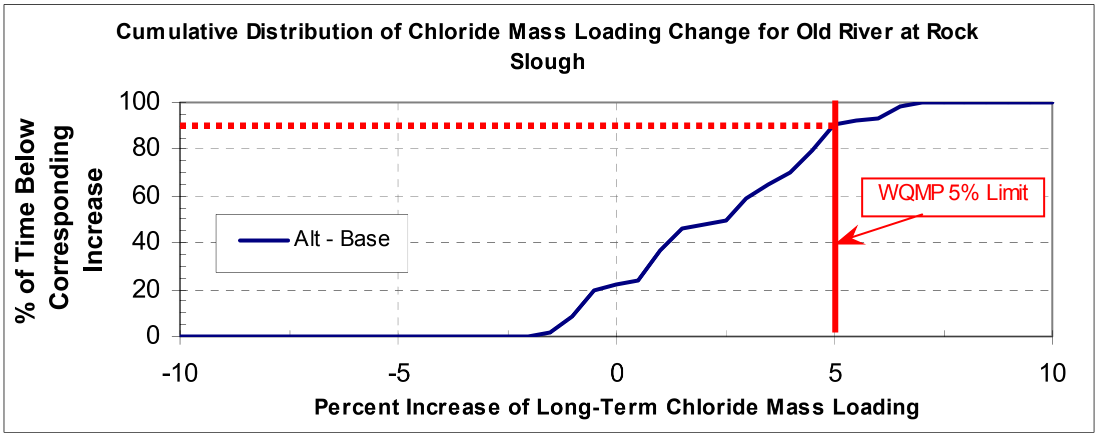

Figure 4.22: Cumulative Distribution of Long-Term Chloride Mass Loading Change for Old River at Rock Slough.

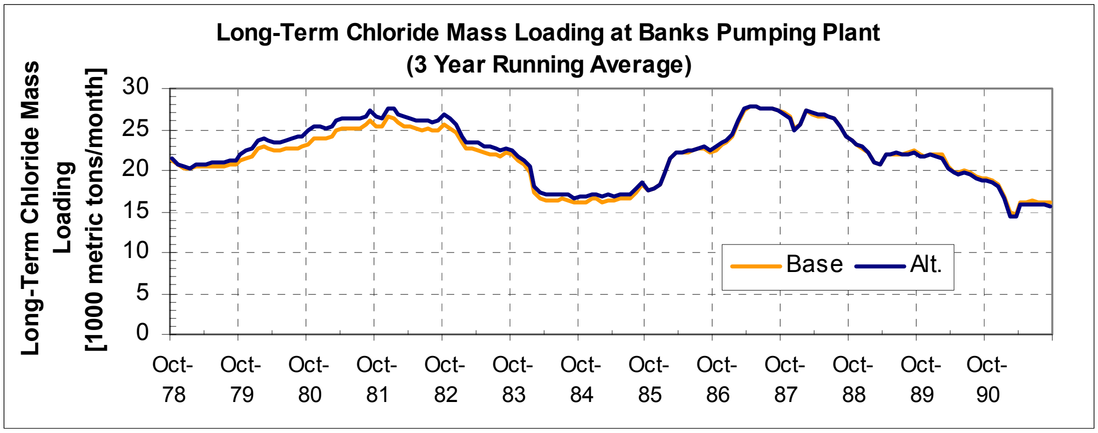

Figure 4.23: Long-Term Chloride Mass Loading for Banks Pumping Plant.

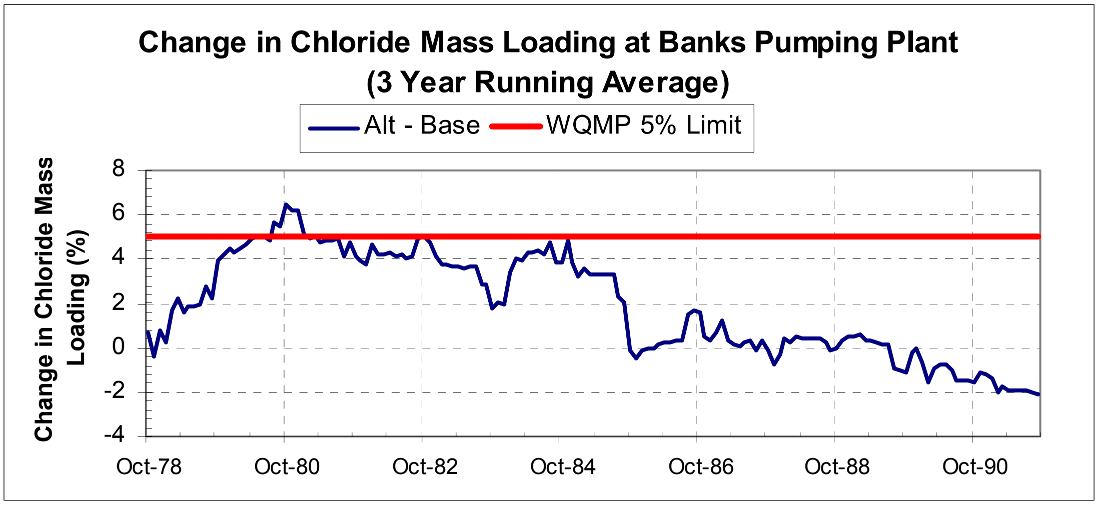

Figure 4.24: Change in Long-Term Chloride Mass Loading for Banks Pumping Plant.

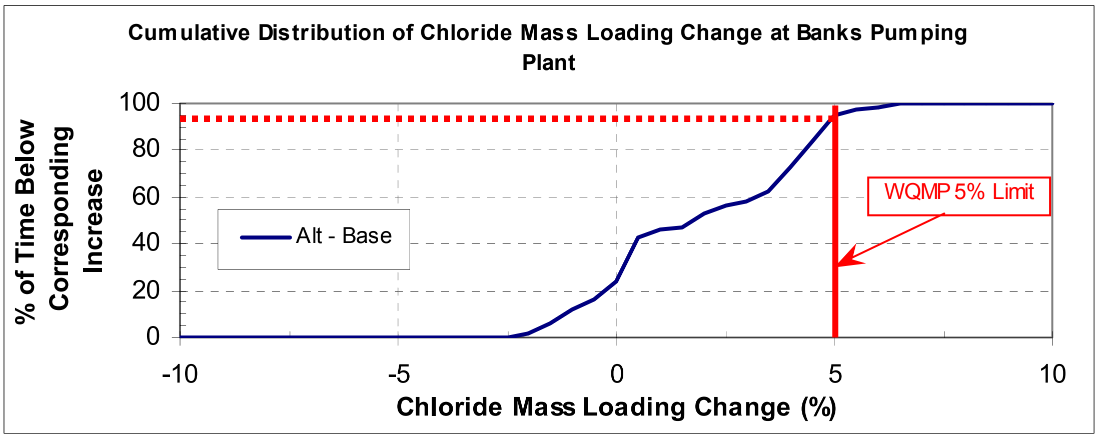

Figure 4.25: Cumulative Distribution of Long-Term Chloride Mass Loading Change for Banks Pumping Plant.

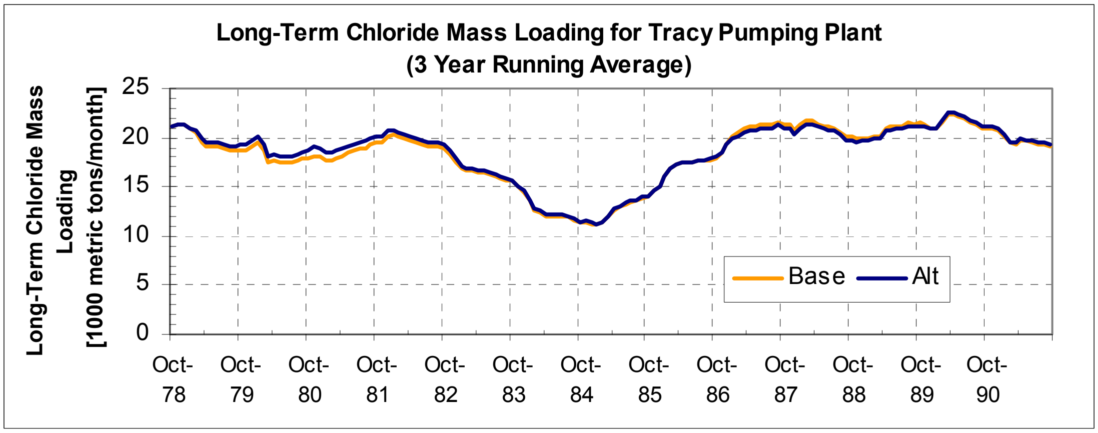

Figure 4.26: Long-Term Chloride Mass Loading for Tracy Pumping Plant.

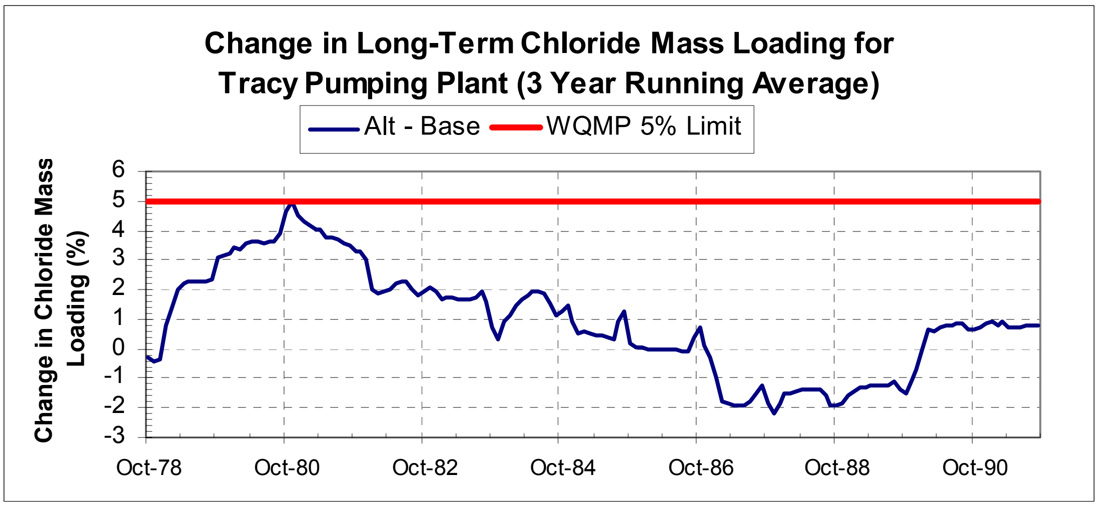

Figure 4.27: Change in Long-Term Chloride Mass Loading for Tracy Pumping Plant.

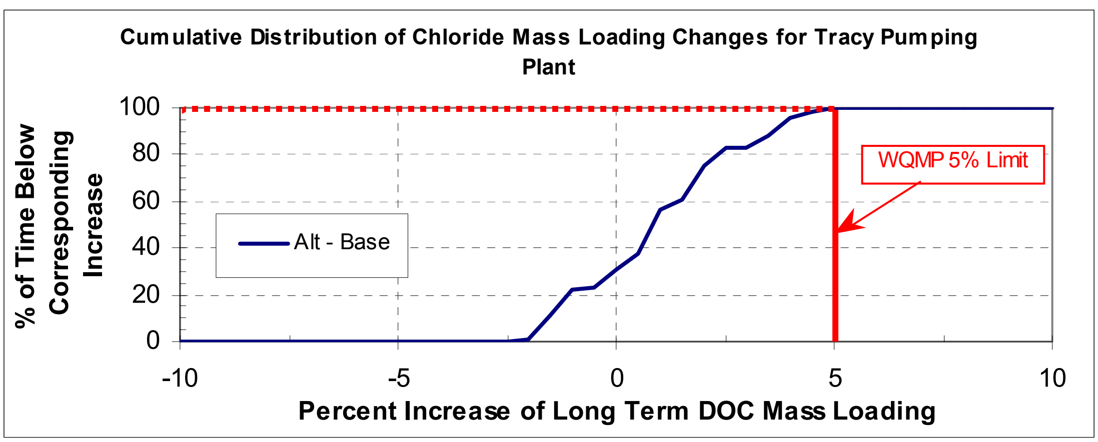

Figure 4.28: Cumulative Distribution of Long-Term Chloride Mass Loading Change for Tracy Pumping Plant.

4.3 DOC

As discussed in Section 3.2.2, QUAL was modified to simulate increases in DOC related to the use of the project islands as reservoirs. Two bookend values were chosen to represent realistic upper and lower bounds of reservoir based growth in DOC. The impact of these modifications on DOC in both Bacon Island and Webb Tract are shown in Figures 4.29 and 4.30. The maximum-modeled DOC in the project islands was 10 and 22 mg/l for the low and high bookend conditions respectively.

When water was diverted into the reservoirs, the DOC in the reservoirs was recalculated using Equation 1 with new initial conditions (the current stage in the reservoir and the DOC concentration of the incoming diversion). The DOC in the reservoirs continued to grow at a rate specified by Equation 1 until the next diversion. This can be best seen in Figure 4.29a, where each drop in Bacon Island DOC corresponds with a diversion into the reservoir.

In some cases the incoming DOC from neighboring channels was higher than the asymptotic (theoretical maximum) value for the low-bookend. The parameters used in Equation 1 could result in the DOC growth formulation effectively removing or lowering the DOC concentration in an island reservoir if the concentration of an incoming diversion was higher than the theoretical maximum. For example, it is shown in Figure 4.29a that the low-bookend DOC tends to flatten out around 6.3 mg/l. Based on the parameters chosen for the low-bookend (see Section 3.2.2) and the depth of Bacon Island during a typical diversion period, the maximum low-bookend should be around 6.3 mg/l. However, there are a few periods in which the low-bookend DOC shown in Figure 4.29a exceeds 8 mg/l. The incoming DOC at these times was greater than 6.3 mg/l. In the original post-processing (these results are not shown) of the DSM2 results, the low-bookend application of Equation 1 then slowly lowered the DOC concentration in Bacon Island until it once again reached the theoretical maximum of 6.3 mg/l. Instead of DOC growing, the DOC in Bacon Island appeared to decrease over time.

Since the purpose of Jung's DOC growth function was to account for increases in DOC concentration due to interactions between water and the peat soil of the island reservoirs, a third simulation where no DOC growth was accounted for was also run. In this third QUAL simulation, the DOC concentration in the island reservoirs would only be a function of the DOC concentration of incoming diversions and the DOC concentration already present in the island reservoirs. This simple mixing formulation is consistent with conservative water quality constituents, and was described by Equation 2 in Section 4.1.

The time series of low-bookend DOC was then compared with the no growth DOC time series. For the few times that the no growth DOC time series was greater than the low-bookend DOC time series (and this would only happen when the implementation of Equation 1 resulted in reductions of island DOC concentrations), the no growth DOC time series data were used instead of the low-bookend data.

The concentration of any release from either island can be found by simply looking at the reservoir concentration at the time of the release. It is important to note that the majority of the releases did not occur when either island's DOC had yet reached its maximum values. The operations provided by CALSIM II resulted in carry-over storage in 1983 (i.e. water was stored in Bacon Island and Webb Tract for more than one year). The summer releases in 1984 from both islands were at the maximum DOC levels described above (NOTE: these 1984 releases did exceed the DOC standards, however, they do not represent the maximum violations of the WQMP standards, as will be described below).

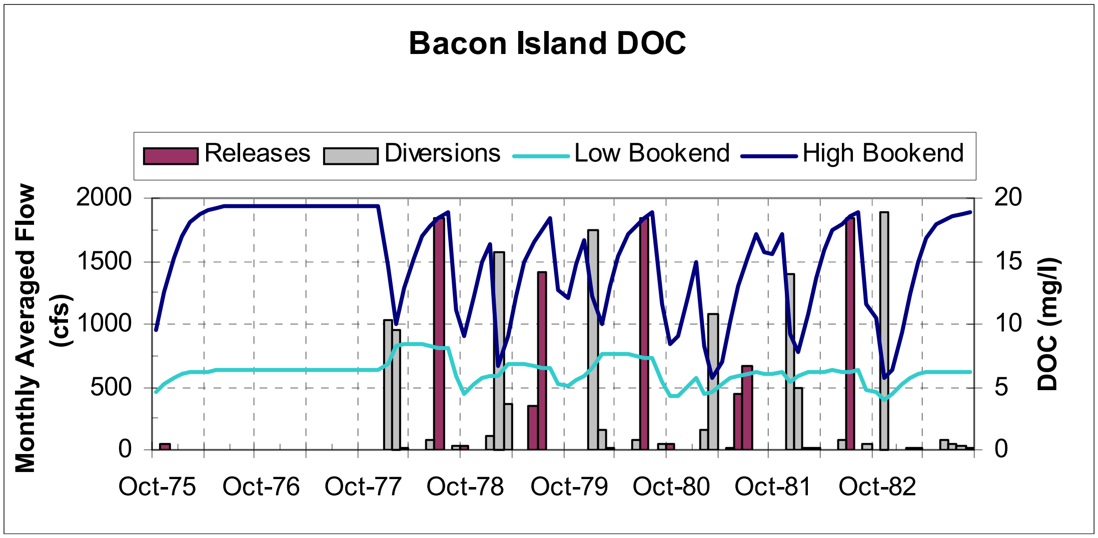

Figure 4.29a: Bacon Island DOC 1975 – 1983.

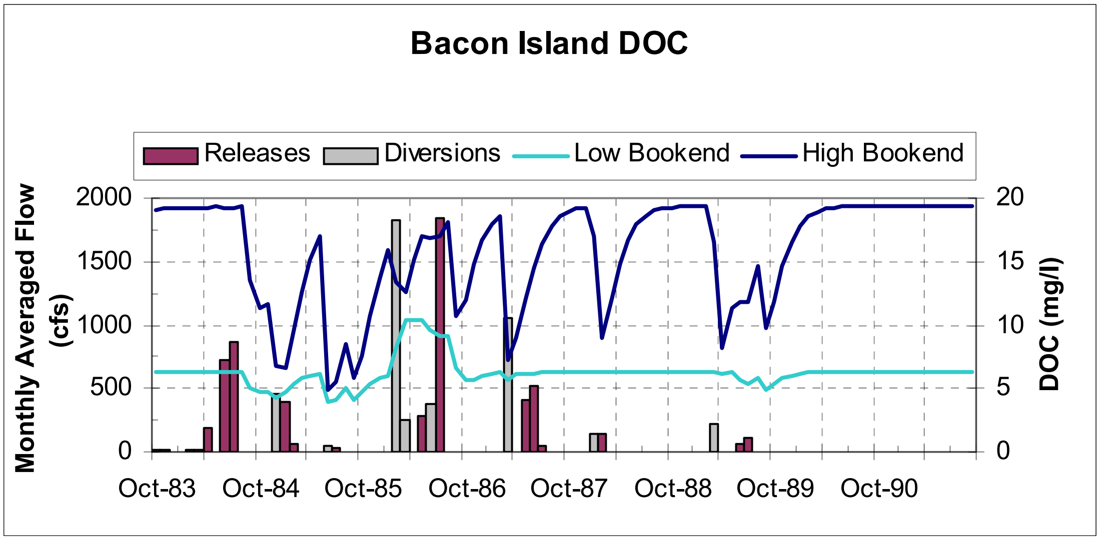

Figure 4.29b: Bacon Island DOC 1983 – 1991.

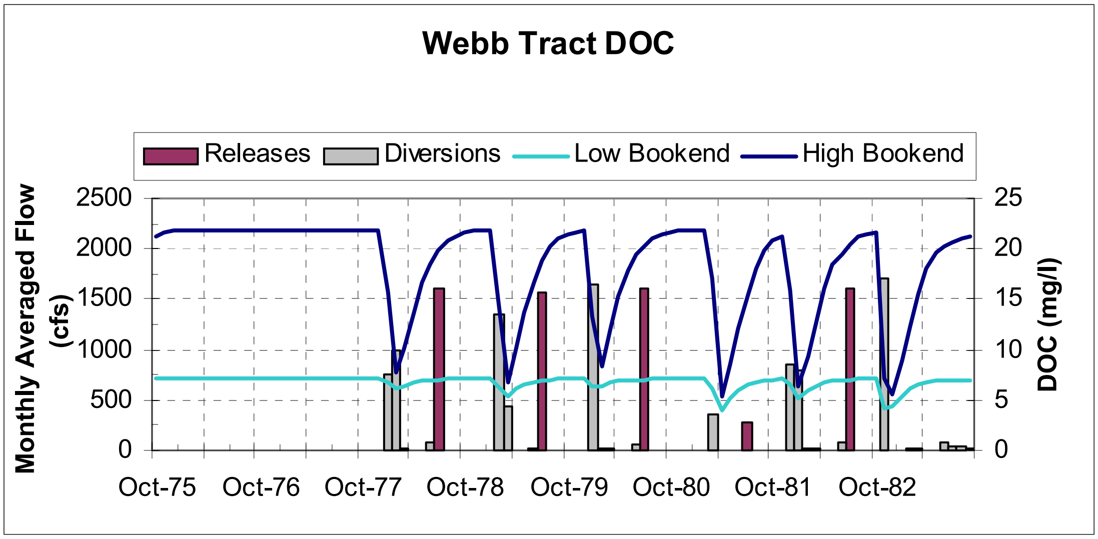

Figure 4.30a: Webb Tract DOC 1975 – 1983.

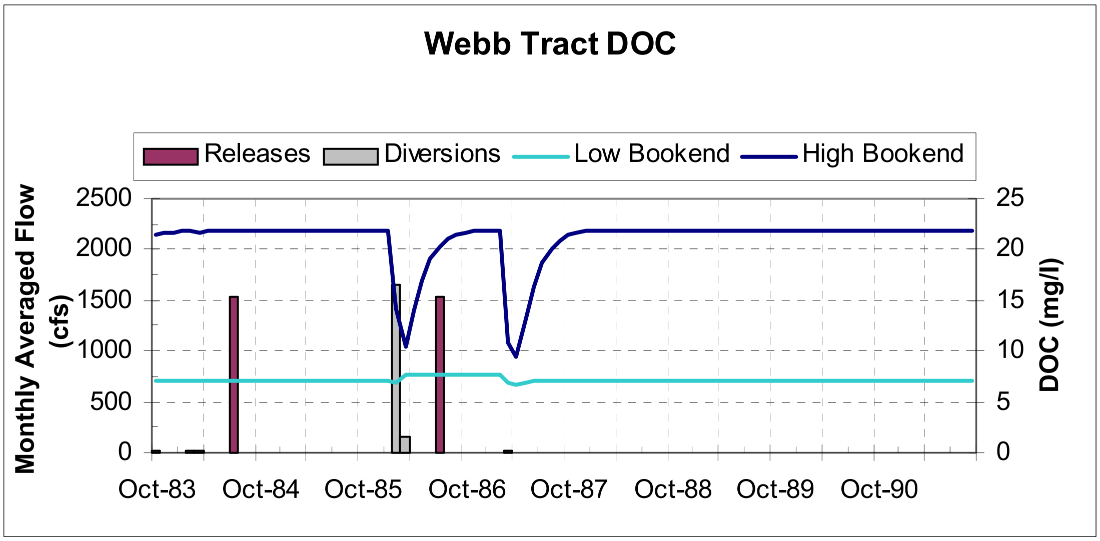

Figure 4.30b: Webb Tract DOC 1983 – 1991.

As discussed in Section 2.2, the consumptive use of both the project and habitat islands was modified to account for local changes in land use. These changes did not decrease the overall consumptive use in the Delta, but instead redirected water use from the project and habitat islands to other locations (see Section 2.2.4 for more details). Clearly these changes will have some impact on both hydrodynamics and water quality. However, the impact of similar changes to consumptive use on just the project islands was found to have a relatively small benefit (Mierzwa, 2001).[15]

Figures 4.32, 4.35, 4.38, and 4.41 illustrate the sensitivity to DOC release concentrations at each of the four urban intake locations: Old River at Rock Slough, Old River at the Los Vaqueros

[15] It is recommended that future studies be conducted without operation of the project, but accounting for changes in land use associated with the project. These studies could quantify the actual ag credit associated with changing the consumptive use of both the project and habitat islands.

Intake, the State Water Project intake at Banks Pumping Plant, and the Central Valley Project intake at Tracy. A 4 mg/l DOC concentration is shown, which was later used to calculate the WQMP change in DOC constraint.

The base case monthly averaged DOC concentration at Rock Slough ranged between 2.08 and 8.42 mg/l. Further south at the other three intake locations, the base case monthly averaged DOC concentrations increased slightly. The base case DOC frequently exceeded the 4 mg/l concentration level at all four locations. During the times when the base case DOC exceeded the 4 mg/l concentration level, both the low- and high-bookend simulations also exceeded 4 mg/l. However, releases from the project also resulted in additional times when the alternative simulations exceeded 4 mg/l. The maximum monthly averaged DOC at all four export locations over the entire 16-year planning study is summarized in Table 4.8.

Table 4.8: Maximum Monthly Averaged DOC (mg/l).

Location	*Base*	*Low Bookend*	*High Bookend*
Old River at Rock Slough	8.42	7.73	7.73
Old River at Los Vaqueros Intake	8.81	8.19	8.19
Banks Pumping Plant (SWP)	10.01	9.50	9.50
Tracy Pumping Plant (CVP)	10.39	10.10	10.10

In all three simulations, the periods of maximum DOC for all of the locations coincided with the high runoff periods that start in the late winter and last through the spring. These periods of high DOC did not coincide with the major (summer) release periods associated with the operation of the project. Though summer project releases from the two alternative simulations did result in additional DOC spikes that approached the winter DOC maximums listed above, the concentration from the project releases did not exceed the maximums for either bookend. However, previous DSM2 studies have shown that other Delta Wetlands configurations can result in conditions where the summer project releases for both bookends can exceed the winter DOC concentrations (Mierzwa, 2001).

Table 4.9: Maximum Monthly Averaged Increase in DOC (mg/l).

Location	*Low - Base*	*High - Base*
Old River at Rock Slough	0.63	2.92
Old River at Los Vaqueros Intake	0.98	3.60
Banks Pumping Plant (SWP)	1.37	4.30
Tracy Pumping Plant (CVP)	1.36	4.21

As shown in Figures 4.29 and 4.30, the quality of the water released from the project islands typically ranged between 5 and 20 mg/l, which frequently is higher than the DOC concentration of the water already present in the channels around the project islands. The maximum monthly increase in DOC for each of the bookend scenarios is shown in Table 4.9. At all four intake locations, these increases were directly related to project releases. The largest increases occurred at the Banks Pumping Plant (SWP). Particle Tracking Model (PTM) simulations have shown that when high quantities of water is released from the island reservoirs, and the export capacity of Banks is increased to match this release, a large portion of this additional water ends up at the project pumps. This additional water typically has DOC concentrations equal to or higher than the concentration of the water coming from other sources, thus the largest increases in DOC concentrations were associated with the regions that also had the largest increases in exports. In other words, increased pumping at Banks would pull the water with higher DOC concentrations to both the Banks and Tracy Pumping Plants.

The impact of the project operations is better illustrated in Figures 4.32, 4.35, 4.38, and 4.41 as a time series of the change in monthly averaged DOC (alternative - base). The WQMP limits the maximum increase in DOC due to project operations based on the modeled base case DOC concentration. When the base case DOC is either less than 3 mg/l or greater than 4 mg/l, the maximum increase in DOC is 1 mg/l. When the base case DOC is between 3 mg/l and 4 mg/l, then the alternative DOC can not exceed 4 mg/l (in other words, the maximum allowed increase is the difference between 4 mg/l and the base case). This constraint is shown below in Figure 4.31 and is illustrated in Figures 4.33, 4.36, 4.39, and 4.42 as a changing DOC constraint time series with values between 0 to 1 mg/l.

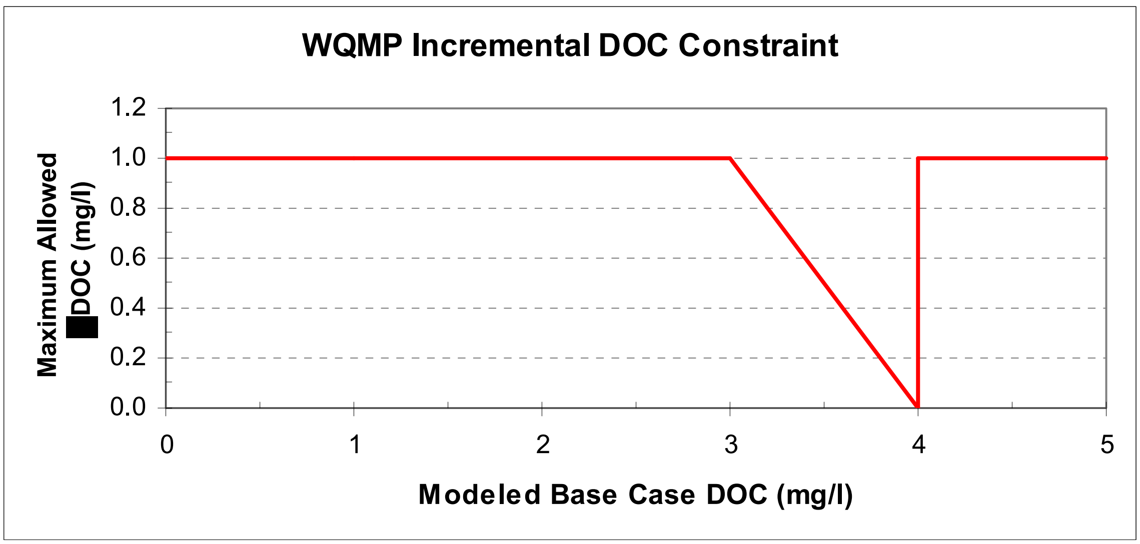

Figure 4.31: WQMP Incremental DOC Constraint.

Both the low- and high-bookend simulations exceeded the WQMP's incremental increase constraint. The low-bookend simulation exceeded the incremental constraint at Banks and Tracy for 4 of the 8 major release periods.[16] The high-bookend simulation exceeded the incremental constraint at all four intake locations for 6 of the 8 major project releases during the 16-year simulation.[17] Typical summer releases were made in July and averaged above 3000 cfs for the

[16] Though during the entire 16-year (192 month) simulation water was released from the project island reservoirs 25 months, the combined flow released from the two project islands exceeded 500 cfs only 9 months or 8 different years (1978, 1979, 1980, 1981, 1982, 1984, 1986, and 1987). In 1979, 1981, 1984 and 1987 water was released in both June and July. June 1984 was the only time when a June release was larger than 500 cfs. These 8 different years are referred to as the major project releases or release periods.

[17] The State Water Project and Central Valley Project exceeded the WQMP constraint for the high-bookend simulation for two months in the same release period (June and July in 1984), bringing the total number of months of violation to 7 for each location.

month. The project releases were less than 1500 cfs, during the two release periods (1981 and 1987) that did not exceed the constraint in the high-bookend simulation.

Frequency histograms of the change in DOC for the entire simulation period were used to create cumulative distribution functions (cdfs) representing the relative change in DOC for each location. These cdfs are shown in Figures 4.34, 4.37, 4.40, and 4.43. On each cdf, a 1 mg/l limit is shown. The point where this limit intersects either of the curves represents the percentage of time that the change in DOC due to the project operations will be equal to or less than the WQMP limit.

For example, according to Figure 4.34, high DOC releases from the project islands will result in changes in DOC at Rock Slough that is equal to or less than 1 mg/l approximately 97% of the time. Similarly, this means that approximately 3% of the time the operation of the project will result in increases in DOC at Rock Slough that are greater than the 1 mg/l WQMP constraint. A summary of the percent of time increases in monthly averaged DOC exceeds the WQMP constraint for the entire simulation period is shown below in Table 4.10. However, as illustrated above in Figure 4.31, sometimes the incremental constraint is less than 1 mg/l, which means that the values shown in Table 4.10 are equal to or less than the percent time that the change in DOC exceeds the WQMP constraint.

Table 4.10: Percent of Time that the Change in DOC is Larger than 1 mg/l.

Location	***% Exceedance Low - Base***	***% Exceedance High - Base***
Old River at Rock Slough	0.0	3.1
Old River at Los Vaqueros Intake	< 0.1	3.1
Banks Pumping Plant (SWP)	0.5	3.6
Tracy Pumping Plant (CVP)	0.5	3.6

The total number of months, out of the 192 months simulated, that exceed the WQMP change in DOC constraint is shown below in Table 4.11. This includes periods when the WQMP change in DOC constraint was less than 1 mg/l. For Banks and Tracy, two of the months this constraint was exceeded occurred in consecutive months of the same year (1984). The number of months that the simulations exceeded 4 mg/l is not shown.

Table 4.11: Number of Months of Exceedance of the WQMP Change in DOC Constraint.

Location	***# Months Low - Base***	***# Months High - Base***
Old River at Rock Slough	0	6
Old River at Los Vaqueros Intake	1	6
Banks Pumping Plant (SWP)	4	7
Tracy Pumping Plant (CVP)	4	7

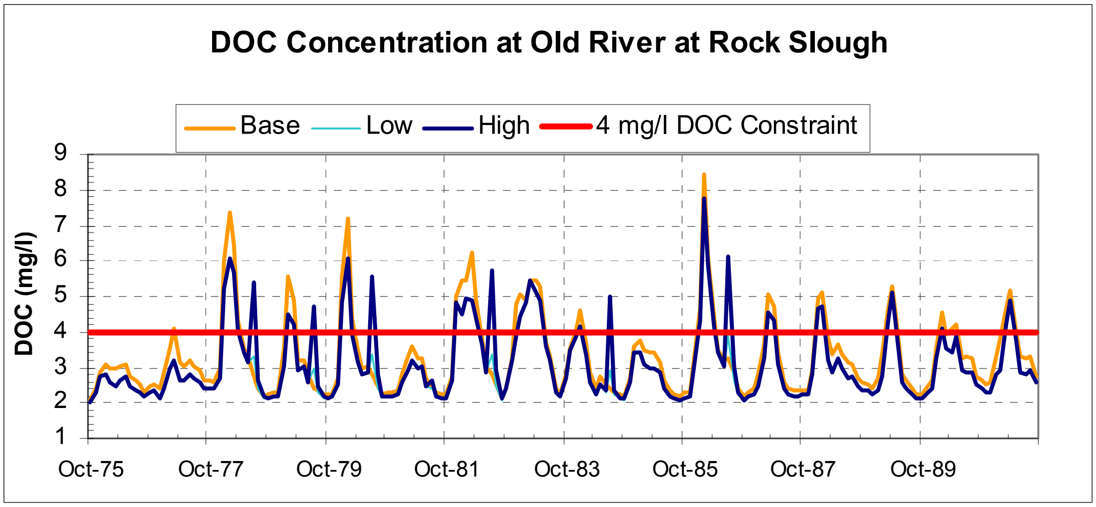

Figure 4.32: DOC Concentration for Old River at Rock Slough.

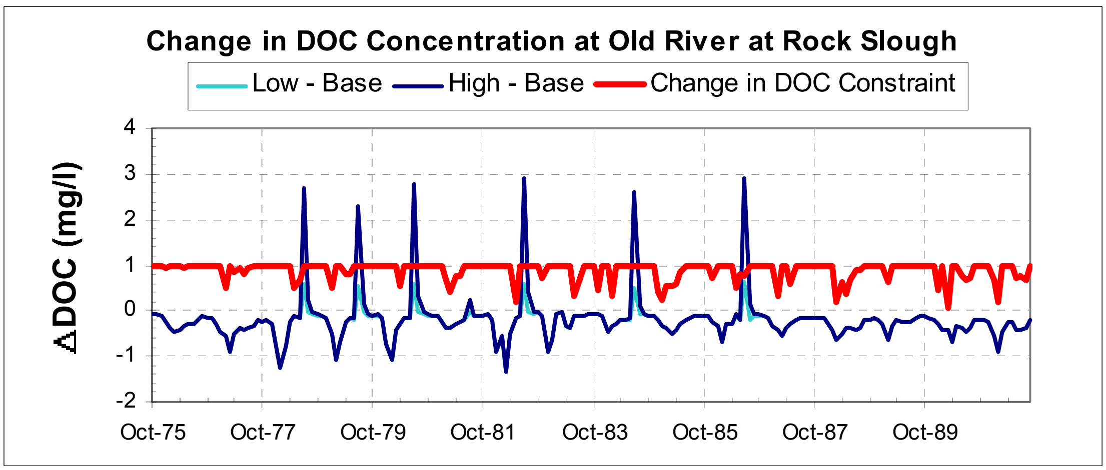

Figure 4.33: Change in DOC for Old River at Rock Slough.

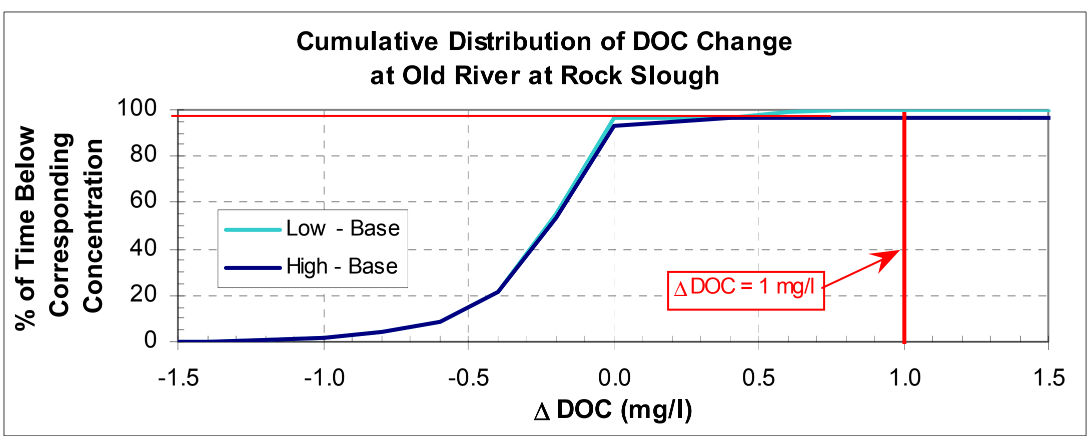

Figure 4.34: Cumulative Distribution DOC Change for Old River at Rock Slough.

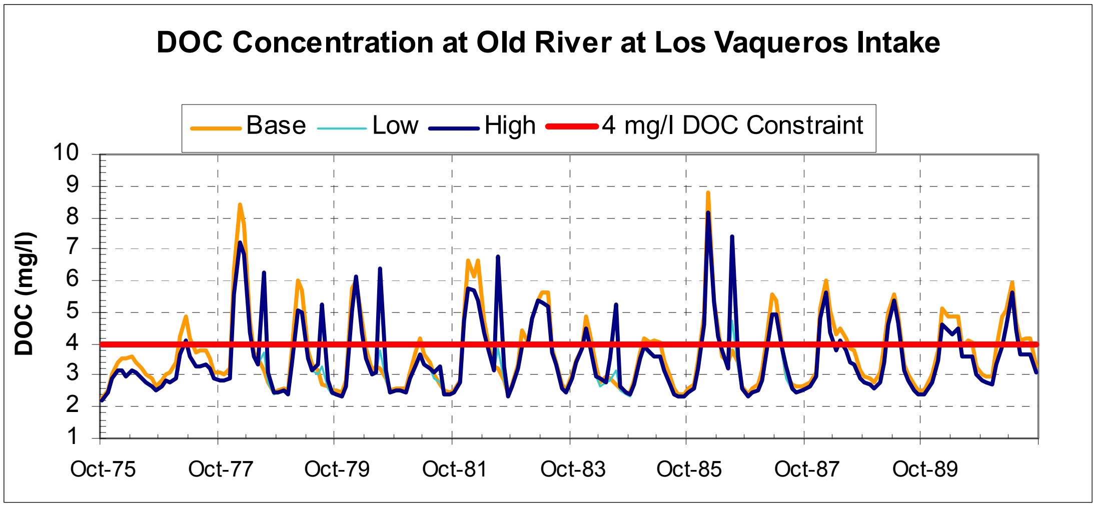

Figure 4.35: DOC Concentration for Old River at Los Vaqueros Intake.

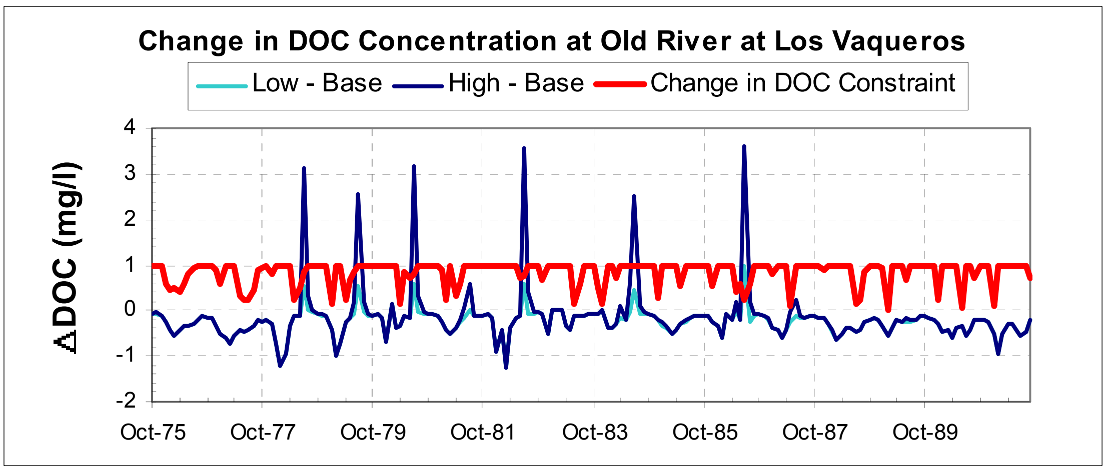

Figure 4.36: Change in DOC for Old River at Los Vaqueros Intake.

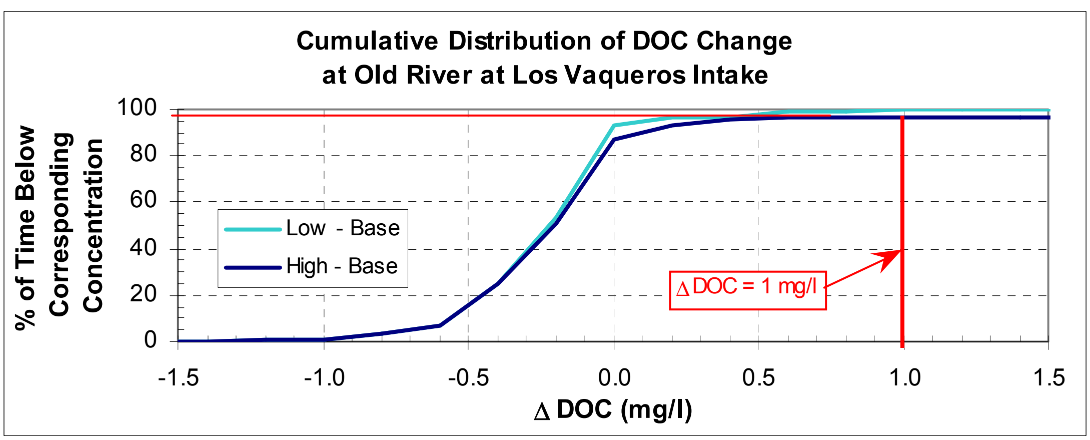

Figure 4.37: Cumulative Distribution DOC Change for Old River at Los Vaqueros Intake.

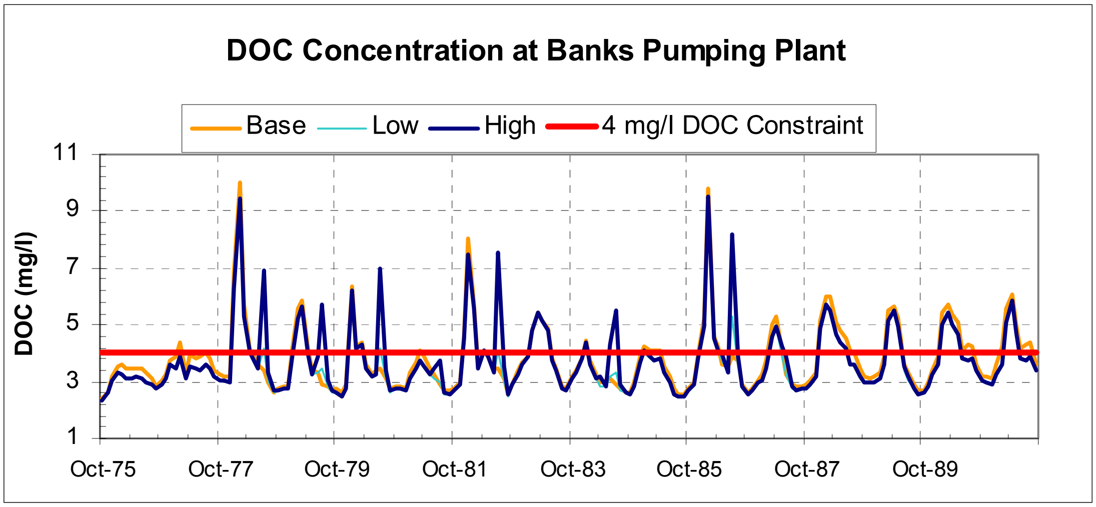

Figure 4.38: DOC Concentration for Banks Pumping Plant.

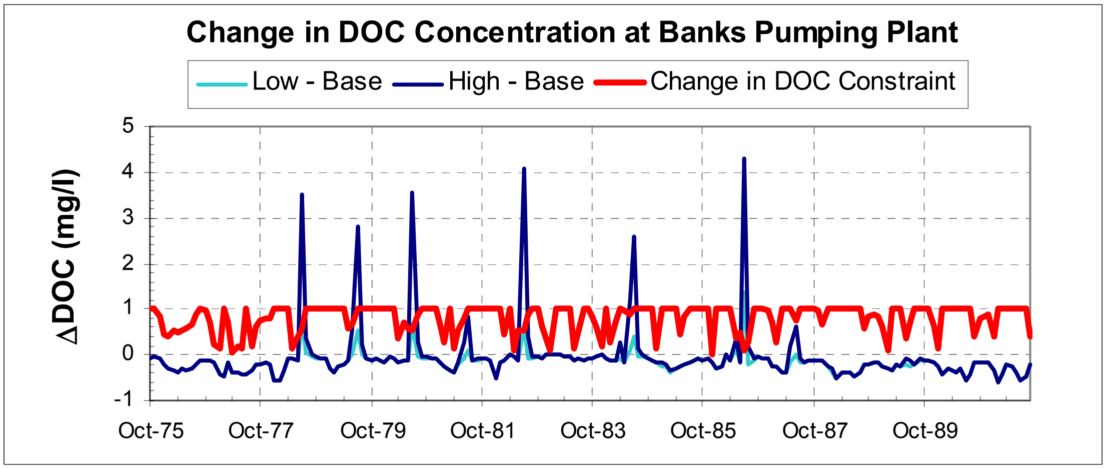

Figure 4.39: Change in DOC for Banks Pumping Plant.

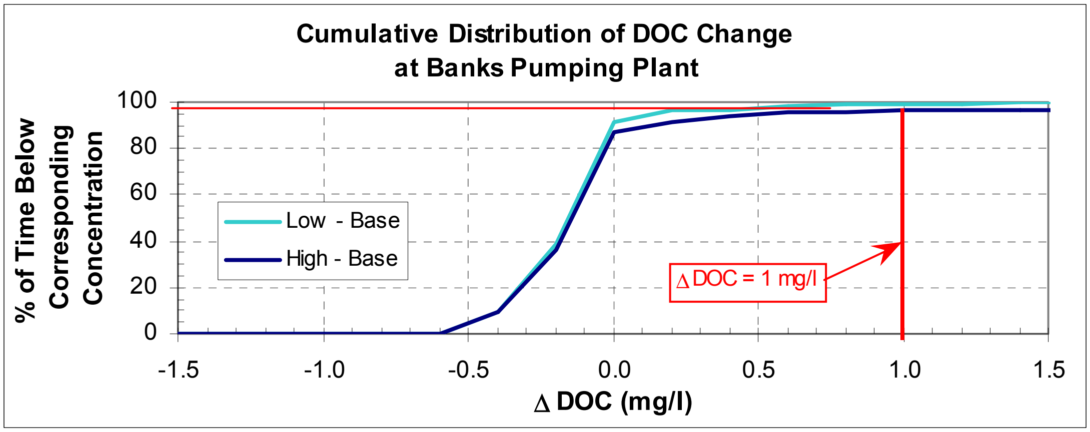

Figure 4.40: Cumulative Distribution DOC Change for Banks Pumping Plant.

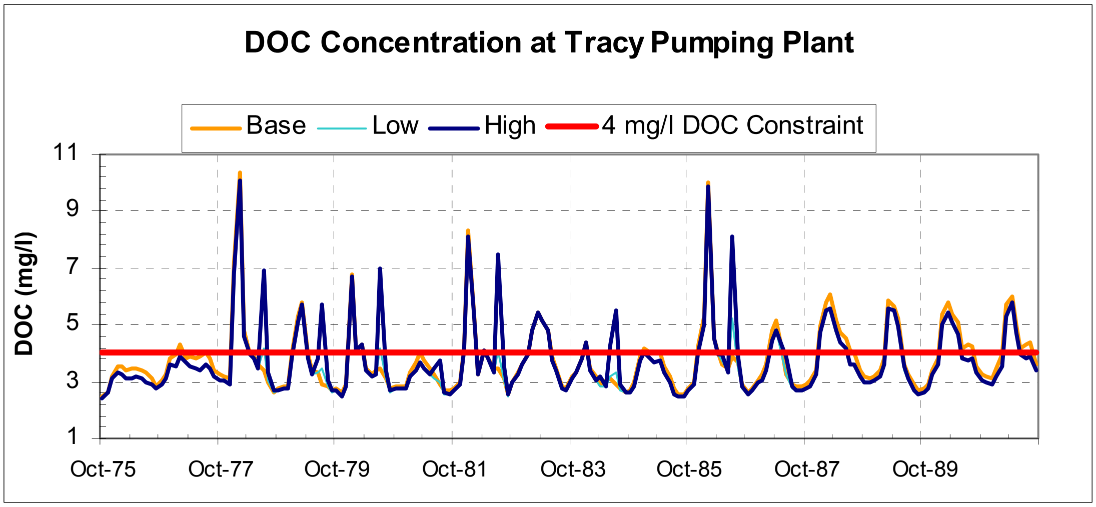

Figure 4.41: DOC Concentration for Tracy Pumping Plant.

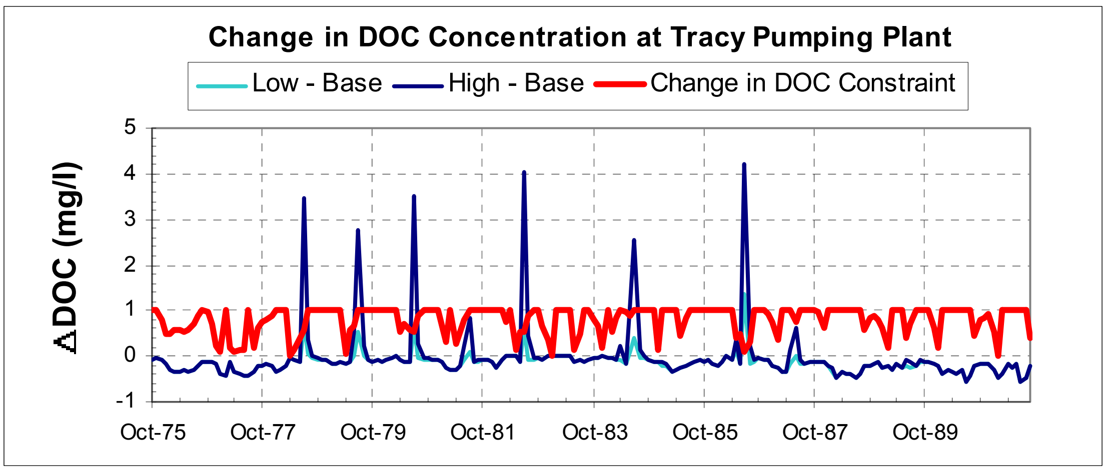

Figure 4.42: Change in DOC for Tracy Pumping Plant.

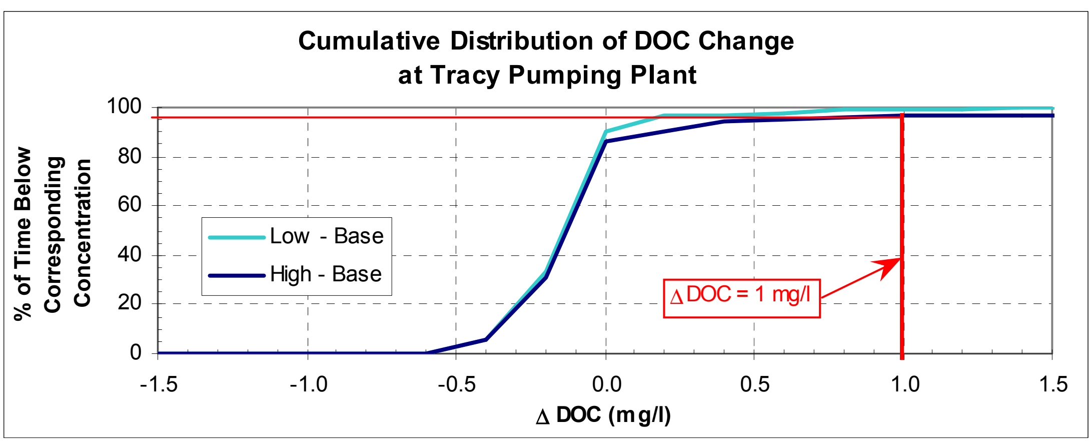

Figure 4.43: Cumulative Distribution DOC Change for Tracy Pumping Plant.

4.4 Long-Term DOC

Long-term increases due to the operation of the project were calculated as the 3-year running average of monthly average DOC mass loading (see Hutton, 2001). Time series plots of the long-term monthly averaged DOC mass loading (expressed in 1000 metric tons / month) at Old River at Rock Slough and the State Water Project and the Central Valley Project intakes are shown in Figures 4.44, 4.47, and 4.50.[18] The long-term impact of the project operations was calculated using Equation 6.

$$\%DOC_{Increase\,w/\,Project} = \frac{DOC_{w/\,Project} - DOC_{w/\,o\,project}}{DOC_{w/\,o\,project}} \times 100\% \qquad \text{[Eqn. 6]}$$

The WQMP limits the long-term DOC mass loading increases at the intake locations due to the project operation to 5%. This 5% limit is shown on the time series plots (Figures 4.45, 4.48, and 4.51) of the long-term percent increase of DOC mass loading. The maximum percent increases in the long-term monthly averaged DOC mass loading is shown in Table 4.12. Only the high-bookend simulations exceeded the WQMP 5% increase constraint for all three locations. The change in long-term monthly averaged DOC mass loading at the Old River at Rock Slough and Tracy Pumping Plant intakes was consistently lower in the low-bookend simulation than in the base case, as is shown by negative maximum increases in Table 4.12.

Table 4.12: Maximum Percent Increase in Long-Term Monthly Averaged DOC Mass Loading.

Location	*Low - Base*	*High - Base*
Old River at Rock Slough	-2.5	9.5
Banks Pumping Plant (SWP)	3.3	12.0
Tracy Pumping Plant (CVP)	-0.5	7.6

Frequency histograms of the percent increase in long-term DOC mass loading for the entire simulation period were used to create cumulative distribution functions (cdfs) to represent the long-term impact of the project operations. These cdfs are shown in Figures 4.46, 4.49, and 4.52. The WQMP maximum 5% increase in long-term DOC mass loading constraint is shown on each figure. The percent of the time that each scenario was equal to or below the WQMP maximum 5% increase constraint is listed in Table 4.13.

[18] Normally Contra Costa Water District (CCWD) diversions are divided between the Rock Slough and Los Vaqueros Reservoir intakes. Long-term DOC mass loading was not calculated for Old River at Los Vaqueros Reservoir intake because CALSIM II did not separate the CCWD diversions. Similarly, the mass loading calculated for Rock Slough is based on the assumption that 100% of CCWD's diversions would be taken at the Rock Slough location.

Table 4.13: Percent Time that the Percent Increase of Long-Term DOC Mass Loading Exceeds the WQMP Maximum 5% Increase Constraint.

Location	*% Exceedance Low - Base*	*% Exceedance High - Base*
Old River at Rock Slough	0	8
Banks Pumping Plant (SWP)	0	50
Tracy Pumping Plant (CVP)	0	25

The total number of months, out of the 156 months simulated, that the long-term increase in DOC mass loading exceeds the WQMP5% maximum increase constraint is shown below in Table 4.14.[19] None of the three intake locations exceeded the 5% increase constraint for the low-bookend. For the high-bookend, all three locations exceeded the 5% increase constraint. The Banks Pumping Plant exceeded the constraint 50 months, the most for any intake location.

Table 4.14: Number of Months that the Increase in Long-Term DOC Mass Loading Exceeds the WQMP 5% Increase.

Location	*# Months Low - Base*	*# Months High - Base*
Old River at Rock Slough	0	12
Banks Pumping Plant (SWP)	0	78
Tracy Pumping Plant (CVP)	0	39

[19] Instead of 192 months, the long-term mass loading calculations used the first 36 months to calculate the running average, thus long-term violations come from a sample of only 156 months.

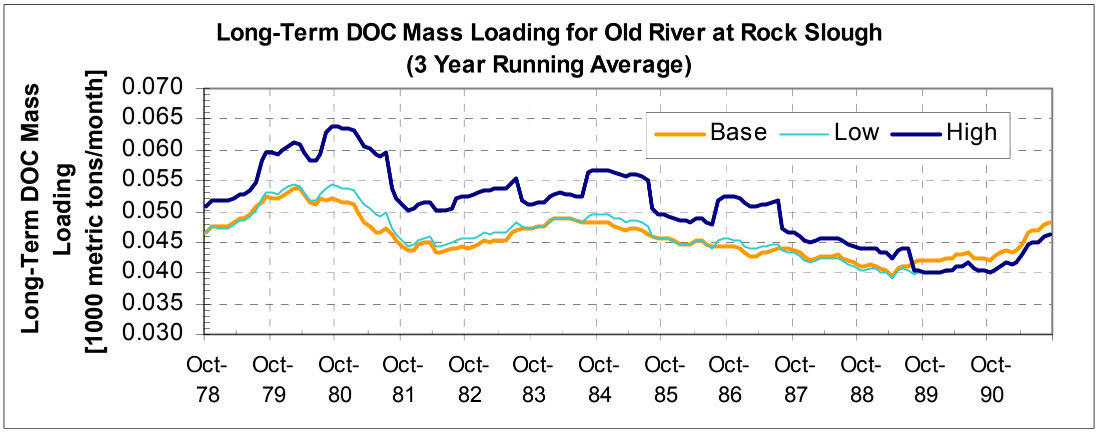

Figure 4.44: Long-Term DOC Mass Loading for Old River at Rock Slough.

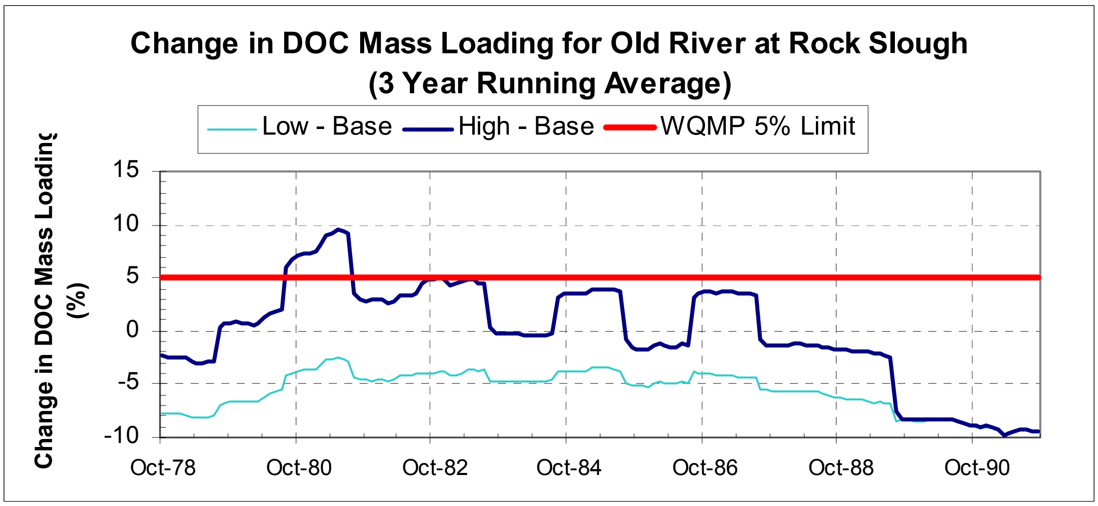

Figure 4.45: Change in Long-Term DOC Mass Loading for Old River at Rock Slough.

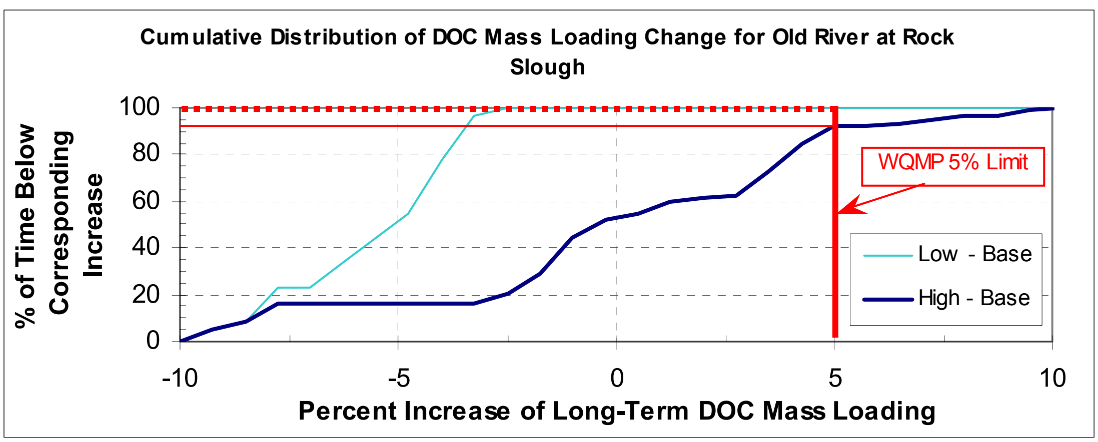

Figure 4.46: Cumulative Distribution of Long-Term DOC Mass Loading Change for Old River at Rock Slough.

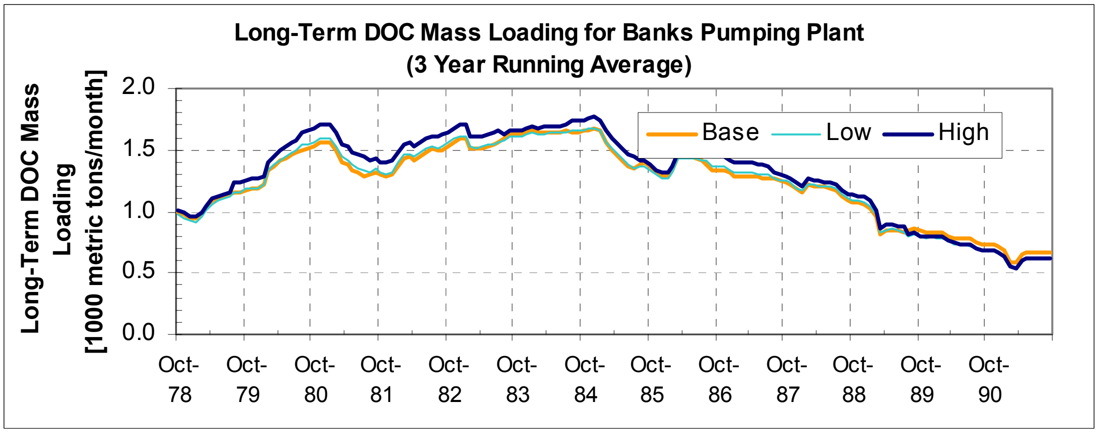

Figure 4.47: Long-Term DOC Mass Loading for Banks Pumping Plant.

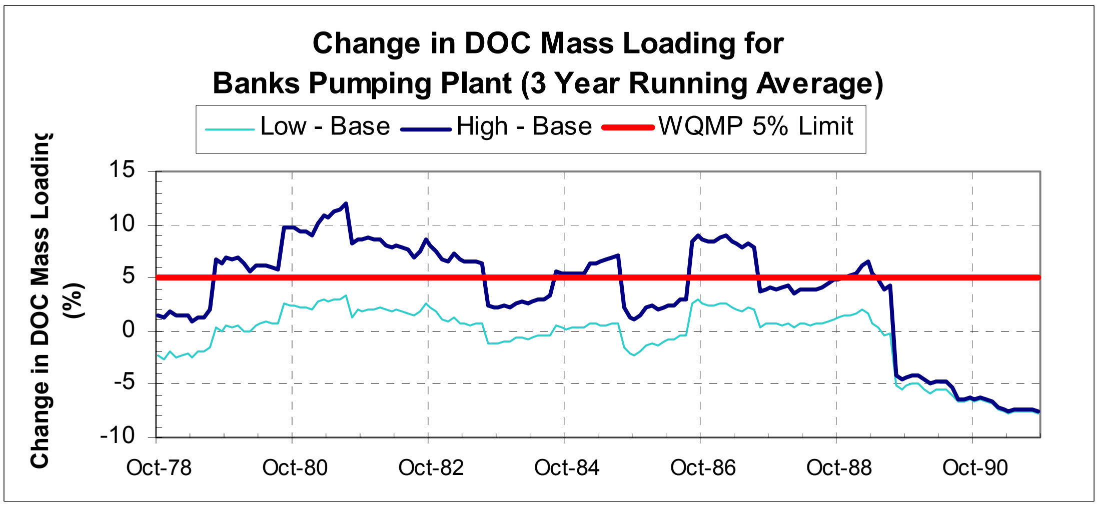

Figure 4.48: Change in Long-Term DOC Mass Loading for Banks Pumping Plant.

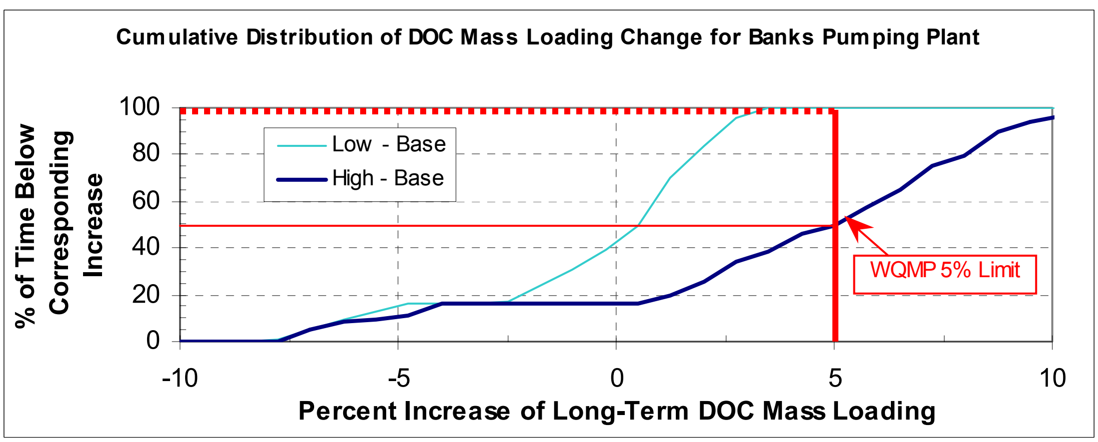

Figure 4.49: Cumulative Distribution of Long-Term DOC Mass Loading Change for Banks Pumping Plant.

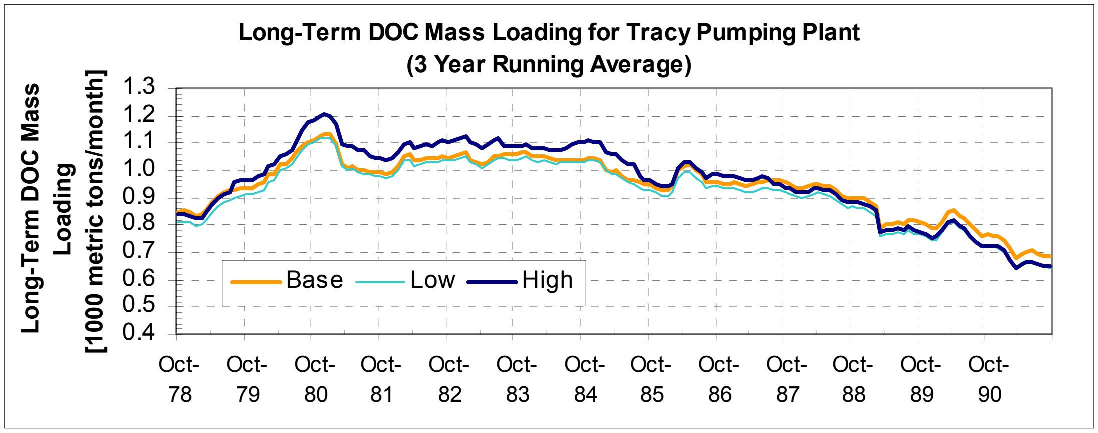

Figure 4.50: Long-Term DOC Mass Loading for Tracy Pumping Plant.

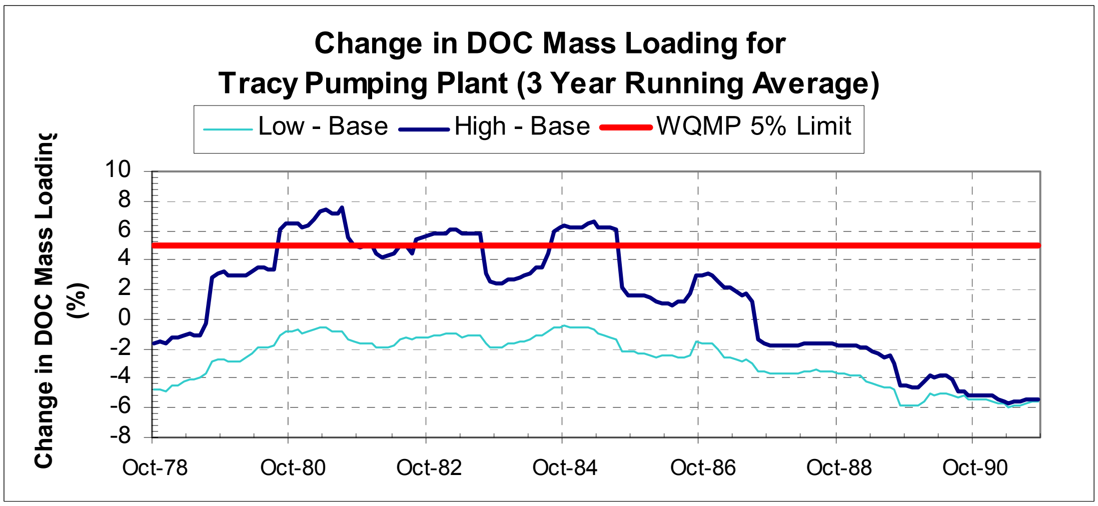

Figure 4.51: Change in Long-Term DOC Mass Loading for Tracy Pumping Plant.

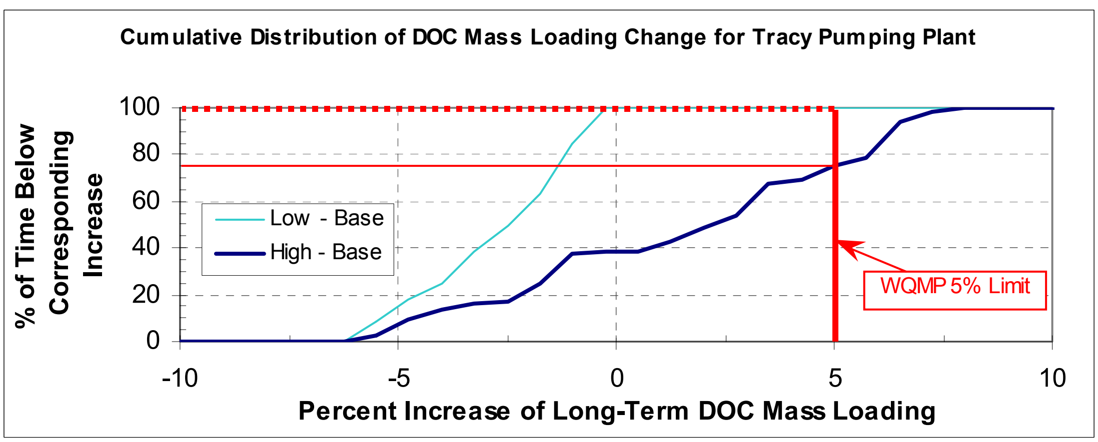

Figure 4.52: Cumulative Distribution of Long-Term DOC Mass Loading Change for Tracy Pumping Plant.

4.5 UVA

Like DOC, storage in a Delta reservoir for several months should increase the UVA measurements. Since the growth formulation modifications made to QUAL only applied to DOC, the UVA results presented here were calculated from the QUAL DOC simulations (see Section 4.3), which accounted for the growth of DOC due to long storage times. Previous work relating DSM2 DOC to UVA results has shown that there is a strong relationship between modeled DOC and UVA at the four intake locations (Anderson, 2001). Anderson developed a linear regression (Equation 7) that was used in this report to convert both the low- and high-bookend DOC results at the four urban intakes to equivalent UVA values.

$$UVA = 0.0435 \times DOC - 0.0347 \qquad \text{[Eqn. 7]}$$

Figures 4.53, 4.55, 4.57, and 4.59 illustrate the sensitivity to UVA release at each of the four urban intake locations: Old River at Rock Slough, Old River at the Los Vaqueros Intake, the State Water Project intake at Banks Pumping Plant, and the Central Valley Project intake at Tracy. In the base case, the periods of high UVA for all of the locations coincided with the high runoff periods that start in the late winter and last through the spring. The maximum monthly averaged UVA for each location is shown in Table 4.15. Both the time series plots and Table 4.15 show that the operation of the project resulted in lower maximum monthly averaged UVA values at the intake locations for the low- and high-bookend simulations.

Table 4.15: Maximum Monthly Averaged UVA (cm^{-1}).

Location	*Base*	*Low Bookend*	*High Bookend*
Old River at Rock Slough	0.33	0.30	0.30
Old River at Los Vaqueros Intake	0.35	0.32	0.32
Banks Pumping Plant (SWP)	0.40	0.38	0.38
Tracy Pumping Plant (CVP)	0.42	0.40	0.40

Figures 4.54, 4.56, 4.58, and 4.60 allow a closer look at the changes between the alternative simulation and the base case simulations. In addition to showing the time series of change between the alternative and base case, the combined project releases and diversions are also plotted. Summer time releases from the project increased the UVA concentration by more than 0.1 cm^{-1} for the high-bookend simulation during 6 of the 8 release periods at all four intake locations. The two remaining periods (summers of 1981 and 1987) had substantially lower project releases.

The maximum monthly averaged increase in UVA at each of the intake locations is shown in Table 4.16. The smallest increase in UVA due to project operation occurred at Old River at Rock Slough. The largest increases in UVA were at Banks and Tracy.

Table 4.16: Maximum Monthly Averaged Increase in UVA (cm^{-1}).

Location	*Low - Base*	*High - Base*
Old River at Rock Slough	0.03	0.13
Old River at Los Vaqueros Intake	0.04	0.16
State Water Project	0.06	0.19
Central Valley Project	0.06	0.18

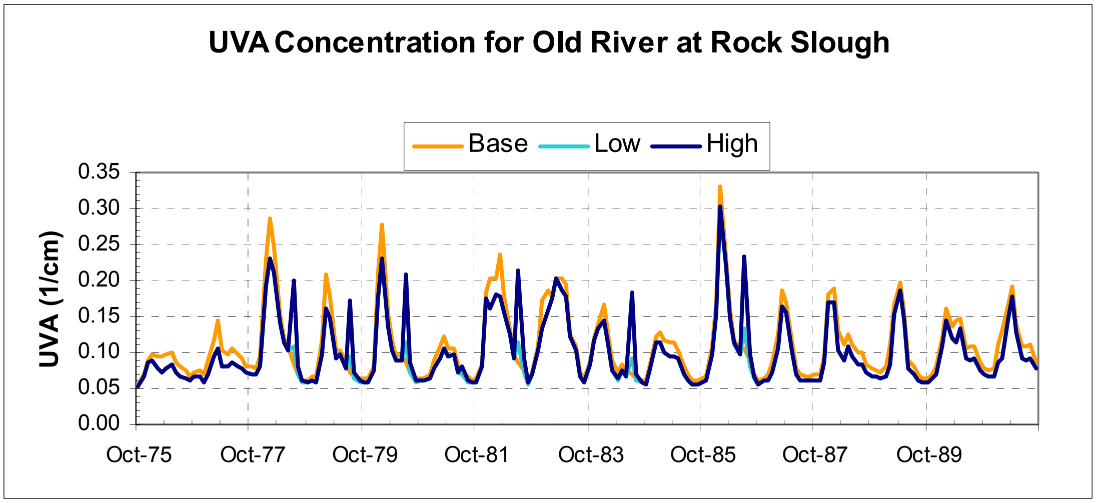

Figure 4.53: UVA Concentration for Old River at Rock Slough.

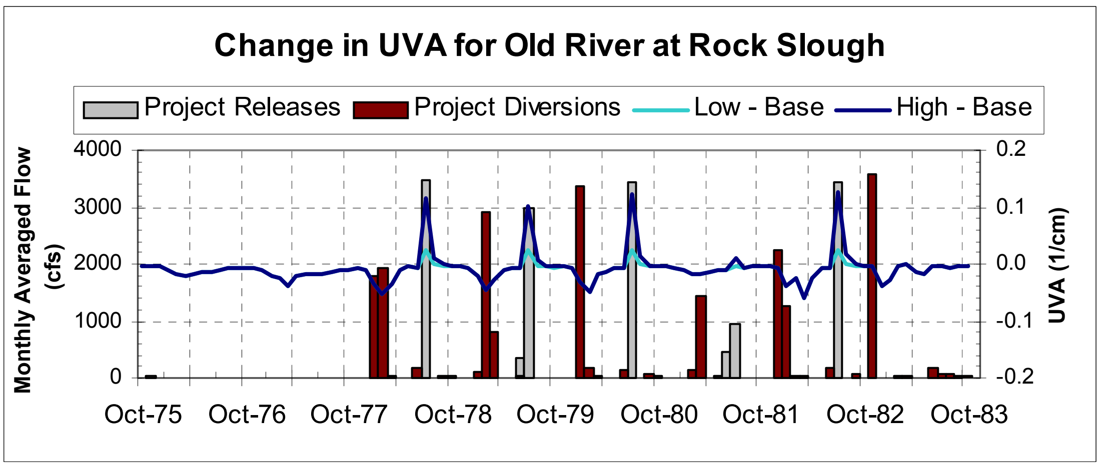

Figure 4.54a: Change in UVA for Old River at Rock Slough for 1975-1983.

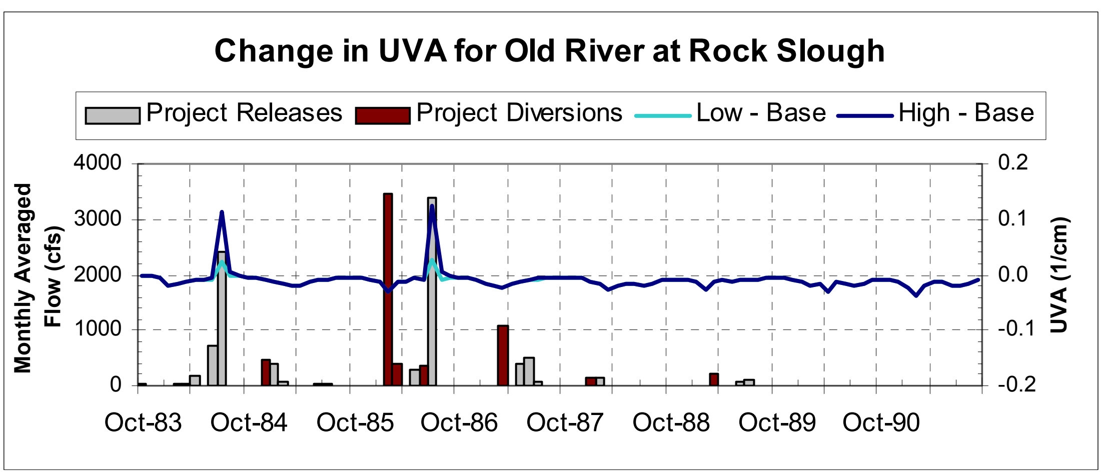

Figure 4.54b: Change in UVA for Old River at Rock Slough for 1983-1991.

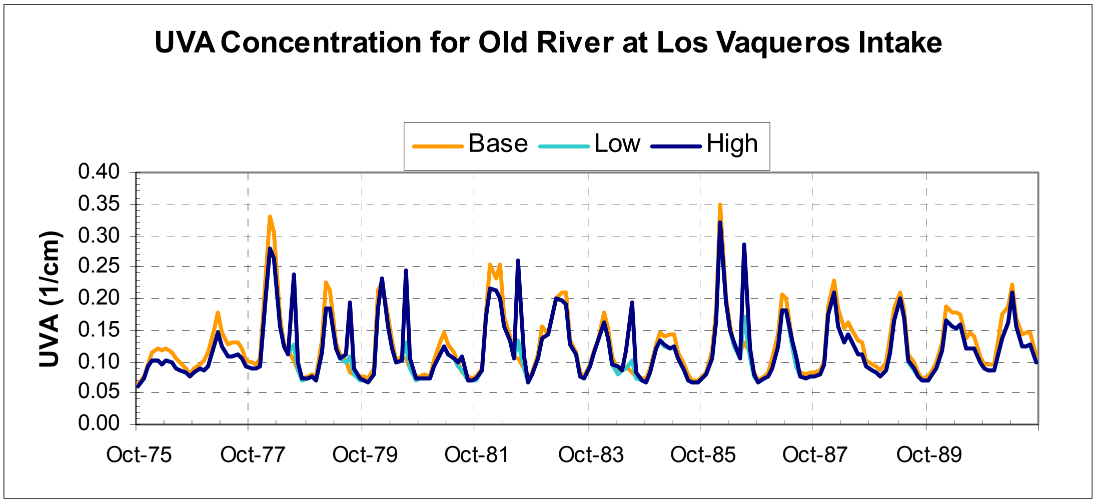

Figure 4.55: UVA Concentration for Old River at Los Vaqueros Intake.

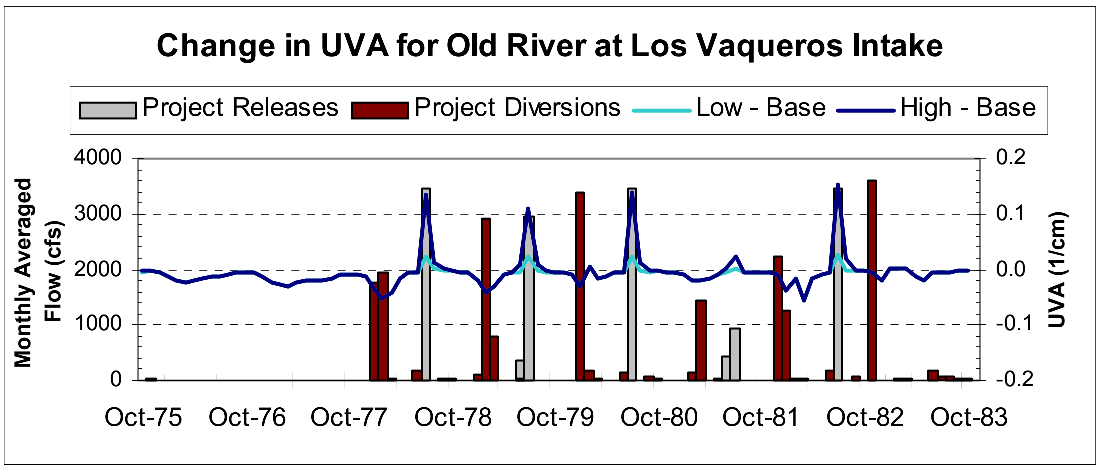

Figure 4.56a: Change in UVA for Old River at Los Vaqueros Intake for 1975-1983.

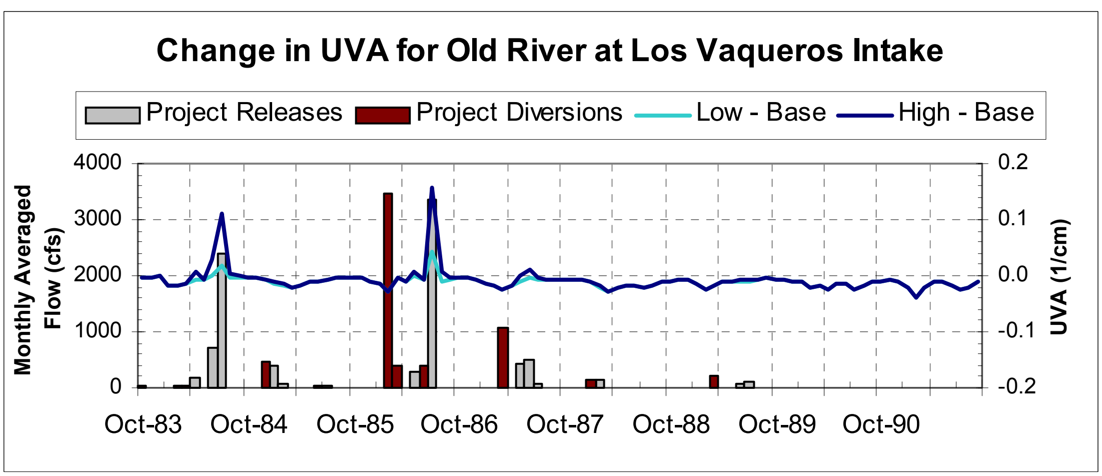

Figure 4.56b: Change in UVA for Old River at Los Vaqueros Intake for 1983-1991.

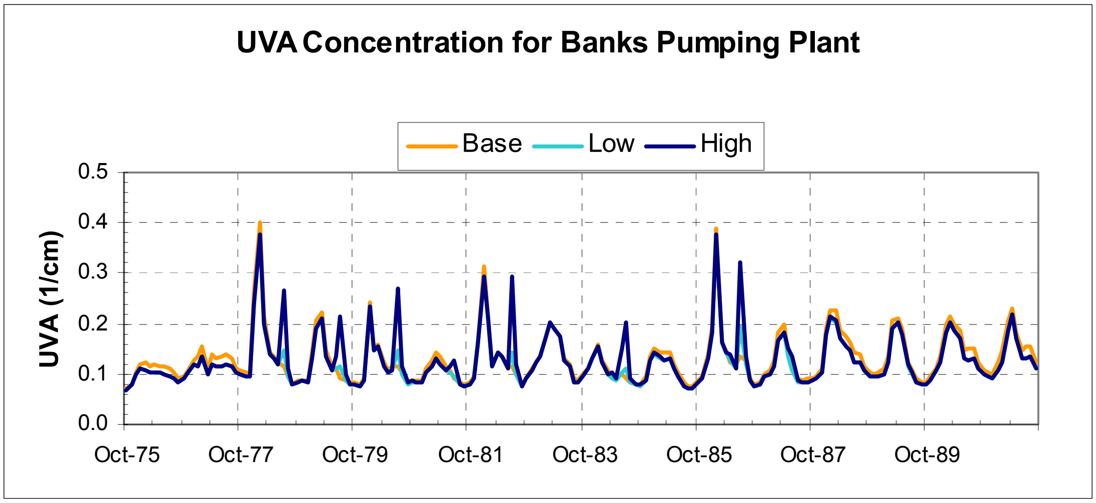

Figure 4.57: UVA Concentration for Banks Pumping Plant.

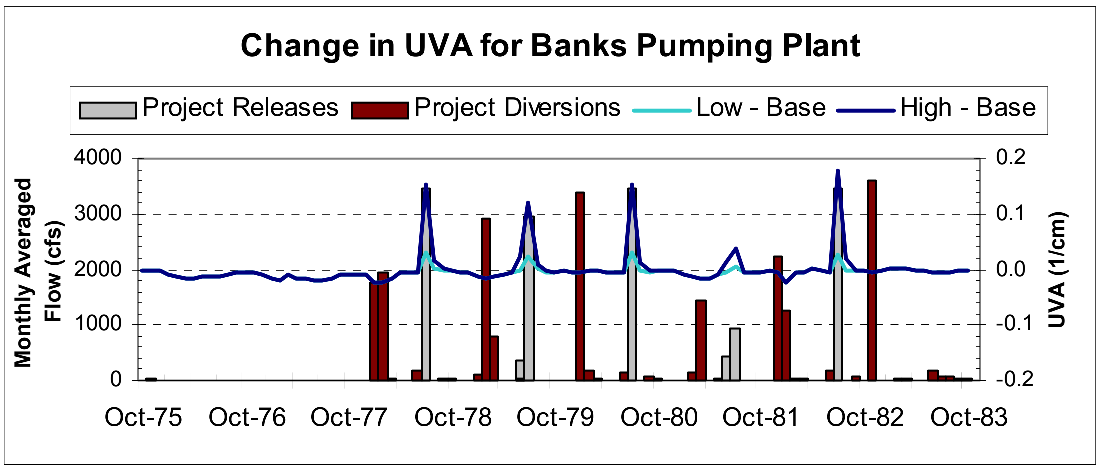

Figure 4.58a: Change in UVA for Banks Pumping Plant for 1975-1983.

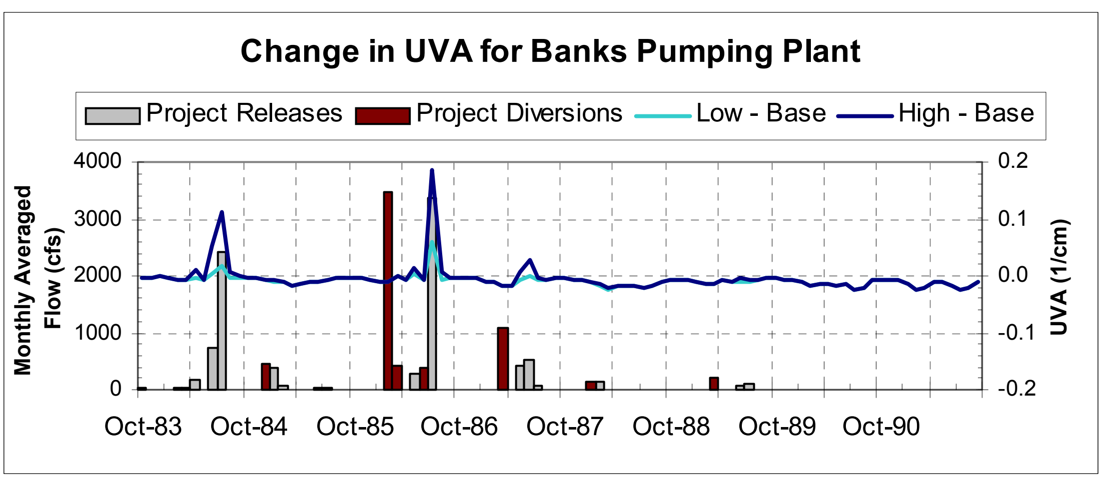

Figure 4.58b: Change in UVA for Banks Pumping Plant for 1983-1991.

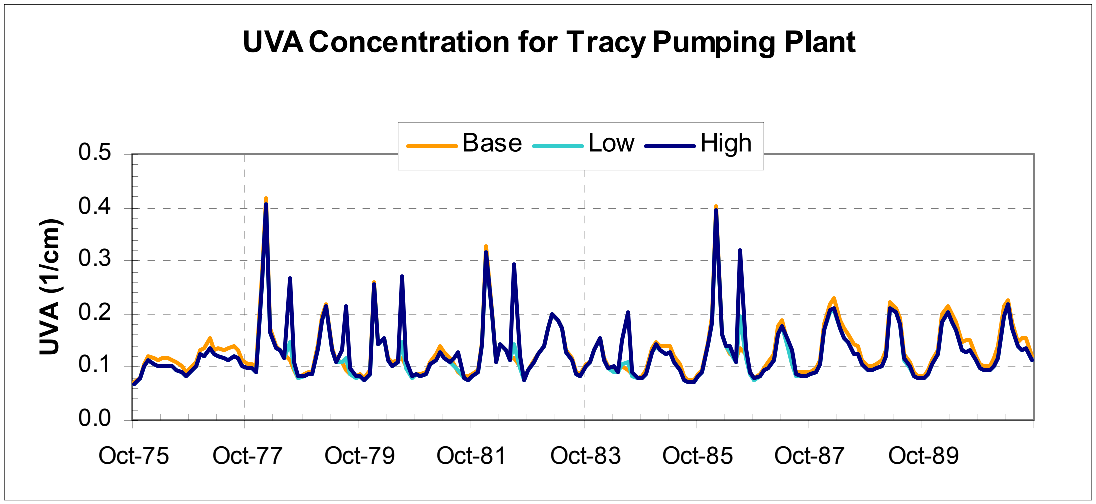

Figure 4.59: UVA Concentration for Tracy Pumping Plant.

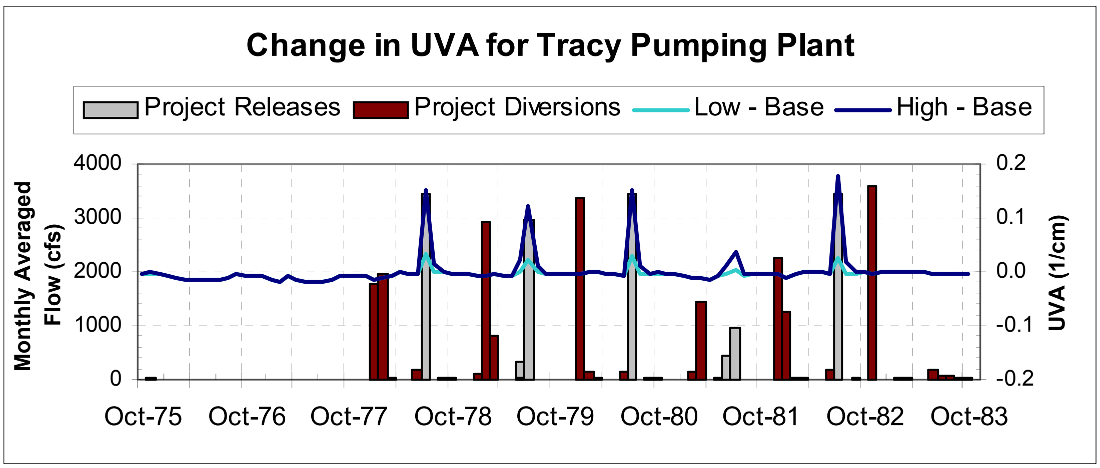

Figure 4.60a: Change in UVA for Tracy Pumping Plant for 1975-1983.

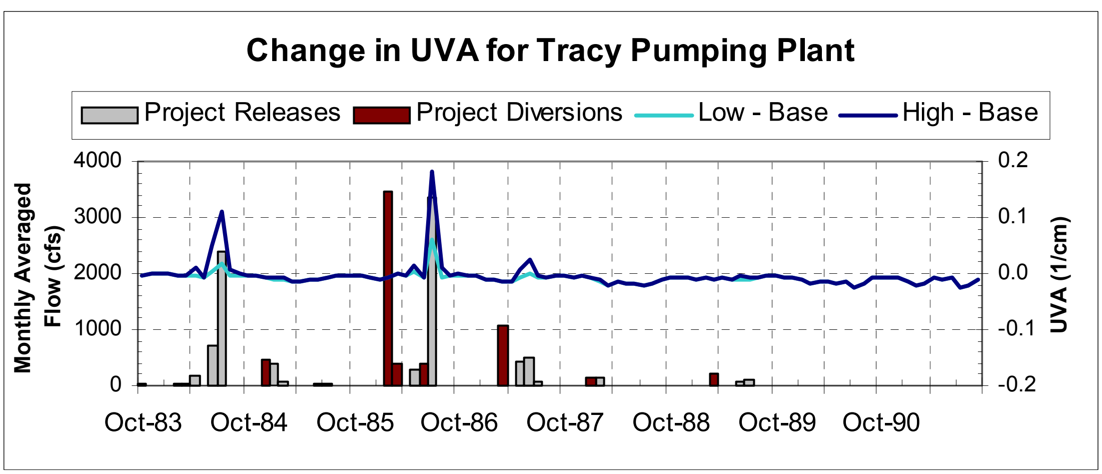

Figure 4.60b: Change in UVA for Tracy Pumping Plant for 1983-1991.

4.6 TTHM

According to the WQMP total trihalomethane (TTHM) formation is limited to 64 ug/l. For periods when the modeled base case exceeds this 64 ug/l standard, the WQMP permitted a 5% increase above the standard (3.2 ug/l) due to operation of the Delta Wetlands project.

Using the EC and DOC low and high bookend results from QUAL, two TTHM bookend values for Old River at Rock Slough were calculated using (Hutton, 2001):

$$TTHM = C_1 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48} \qquad \text{[Eqn. 8]}$$

where

TTHM = total trihalomethane concentration (ug/l),
C_1 = 14.5 when DOC < 4 mg/l,
C_1 = 12.5 when DOC ≥ 4 mg/l,
DOC = raw water dissolved organic carbon (mg/l) from DSM2,
UVA = raw water ultraviolet absorbance at 254 nm (1/cm) from DOC,
Br = raw water bromide concentration (mg/l) as converted from DSM2, and
T = raw water temperature (°C).

The bromide concentration at Rock Slough was developed by Bob Suits (2001b) from regressions of observed (1) Contra Costa Canal Pumping Plant #1 chloride data to Contra Costa Canal Pumping Plant #1 Bromide data, and (2) Contra Costa Canal Pumping Plant #1 chloride data to Rock Slough EC. The bromide relationship used in Equation 8 for Rock Slough is:

$$Br_{Rock\ Slough} = \frac{EC_{Rock\ Slough} - 118.7}{1040.3} \qquad \text{[Eqn. 9]}$$

The bromide relationship for the remaining urban intake locations used in Equation 8 is:

$$Br = \frac{EC - 189.2}{1020.77} \qquad \text{[Eqn. 10]}$$

However, during a few periods QUAL's EC concentrations were so low that using these field conversions the resulting bromide concentrations were too low. A minimum bromide concentration of 0.01 ug/l was assumed during these periods.

The monthly average water temperatures used in Equation 8 are shown below in Figure 4.61. These temperature data came from Contra Costa water treatment plant averages, as provided by K.T. Shum of Contra Costa Water District (Forkel, 2001).

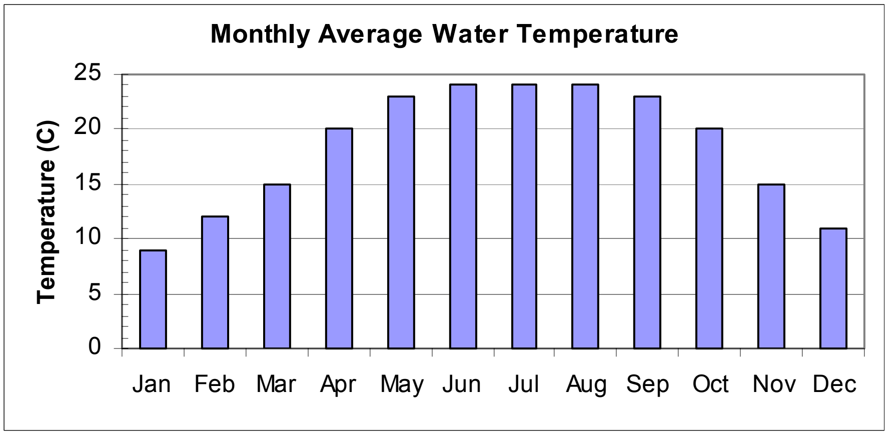

Figure 4.61: Monthly Average Water Temperature.

Using Equations 8, 9, and 10, the TTHM for all the urban intakes was calculated for the entire 16-year simulation period. The sensitivity to DOC and bromide release from the project islands is shown in Figures 4.63, 4.66, 4.69, and 4.72. The 64 ug/l WQMP constraint was exceeded only a few times. The base case exceeded this standard in February 1991 at Old River at Rock Slough. At the Old River at Los Vaqueros Intake, Banks, and Tracy, the only time the base case exceeded the TTHM constraint was in March 1977. Both the bromide and DOC were fairly high during this month. Releases from the projects in both alternatives resulted in increases in TTHM, however, the operation of the project also resulted in some slight reductions in the simulated TTHM concentration. For example, though the base case exceeded the 64 ug/l standard in March 1977 at Banks, both the low- and high-bookend simulations were slightly below this constraint.

The maximum monthly TTHM concentrations for each of the simulations are displayed in Table 4.17. The largest maximum monthly averaged TTHM concentrations for the base case and low- and high-bookend simulations occurred at Tracy in March 1977. Though the maximum monthly TTHM concentration was the same for the low- and high-bookend simulations at Old River at Rock Slough, the Old River at Los Vaqueros Intake, and the Tracy, as was shown in Figures 4.63, 4.66, 4.69, and 4.72, TTHM was different at other times. The high-bookend maximum monthly averaged TTHM concentration for Banks corresponded with a project release month in July 1986.

Table 4.17: Maximum Monthly Averaged TTHM (ug/l).

Location	***Base***	***Low Bookend***	***High Bookend***
Old River at Rock Slough	66.8	57.5	57.5
Old River at Los Vaqueros Intake	79.5	68.3	68.3
Banks Pumping Plant (SWP)	67.0	63.9	64.4
Tracy Pumping Plant (CVP)	84.4	82.0	82.0

Time series plots (see Figures 4.64, 4.67, 4.70, 4.73) illustrating the change between each alternative scenario and the base case provide a more useful tool to assess the impact of the project operation on TTHM formation. Although these plots show the change due to the project operation over the entire simulation period, the intermittent 3.2 ug/l maximum increase in TTHM constraint applies only at the times when the regular 64 ug/l constraint was exceeded by the base case as shown in Figures 4.63, 4.66, 4.69, and 4.72. This maximum increase constraint is only shown on these figures when it applies.

The WQMP constrained the operation of the project such that TTHM concentrations should not exceed 64 ug/l, unless the modeled base case TTHM already exceeds 64 ug/l (Hutton, 2001). When the base TTHM concentration exceeded the 64 ug/l constraint, a fixed allowable increase of 3.2 ug/l applies. When the base TTHM concentration was less than 64 ug/l, the incremental increase was set-up such that the alternative TTHM concentration would not exceed the 64 ug/l constraint. At these times, the incremental constraint is the difference between 64 ug/l and the modeled base case, as is shown in Figure 4.62.

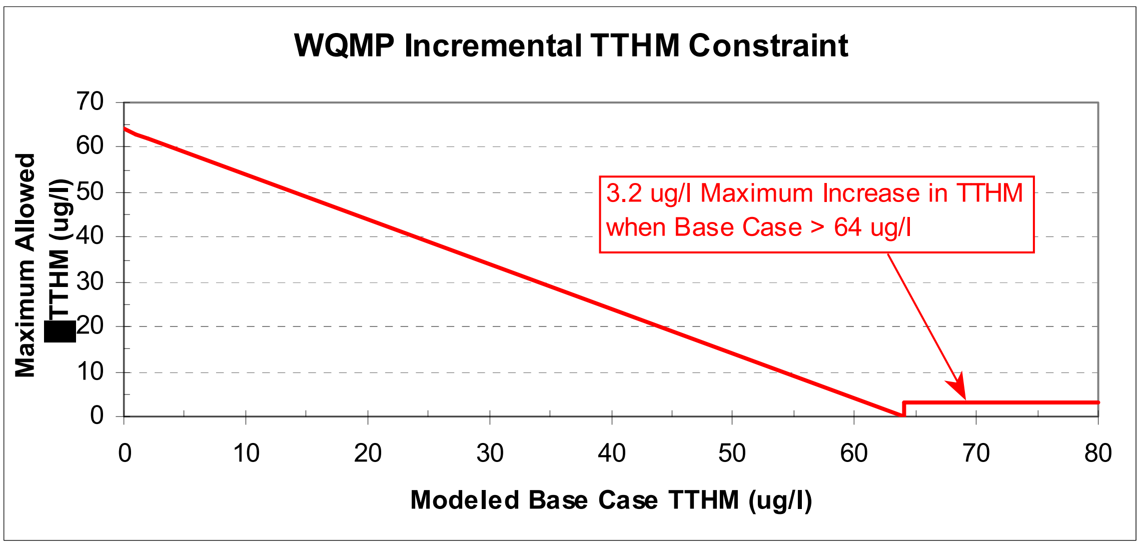

Figure 4.62: WQMP Incremental TTHM Constraint.

The maximum monthly averaged increases at the urban intakes are listed below in Table 4.18. Though the majority of these increases were less than the incremental TTHM constraint illustrated in Figure 4.62, there was one time (at Banks in July 1986) when the base case TTHM concentration was below 64 ug/l and the high-bookend TTHM concentration was greater than 64 ug/l. Otherwise, there were no violations of the incremental TTHM constraint during the course of the 16-year study.

Table 4.18: Maximum Monthly Averaged Increase in TTHM (ug/l).

Location	*Low - Base*	*High - Base*
Old River at Rock Slough	5.65	18.14
Old River at Los Vaqueros Intake	5.10	19.07
Banks Pumping Plant (SWP)	5.27	22.58
Tracy Pumping Plant (CVP)	5.25	22.15

Frequency histograms of the percent increase in TTHM for the entire simulation period were used to create cumulative distribution functions (cdfs). These cdfs are shown in Figures 4.65, 4.68, 4.72, and 4.74. Although a change in TTHM concentration of 3.2 is shown on each figure, the WQMP change in TTHM constraint frequently is much higher than this amount. However, this value, 3.2 ug/l, represents 5% of the 64 ug/l standard and thus is used to illustrate how frequently the change in TTHM is equal to or greater than a 5% change. The percent of time that the change in TTHM concentration is greater than 3.2 ug/l is shown for each location in Table 4.19.

Table 4.19: Percent of Time that the Change in TTHM is Greater Than 3.2 ug/l.

Location	***%Exceedance Low - Base***	***%Exceedance High - Base***
Old River at Rock Slough	5.3	7.7
Old River at Los Vaqueros Intake	3.6	8.0
Banks Pumping Plant (SWP)	2.3	8.5
Tracy Pumping Plant (CVP)	4.1	10.1

The number of months, out of the 192 months simulated, exceeding the WQMP TTHM constraints for both bookend simulations are shown below in Table 4.20. Though times when the simulated TTHM concentrations exceed 64 ug/l are listed, it is the change in TTHM constraint that measures the total number of violations of the WQMP. As discussed above, the only violation occurred at Banks for the high-bookend simulation in July 1986, because the high-bookend TTHM concentration exceeded 64 ug/l when the modeled base case TTHM was less than 64 ug/l.

Table 4.20: Number of Months of Exceedance of the WQMP TTHM Constraint.

	64 ug/l TTHM Constraint			**Change in TTHM Constraint**	
Location	***Base***	***Low***	***High***	***Low***	***High***
Old River at Rock Slough	0	0	0	0	0
Old River at Los Vaqueros Reservoir	1	1	1	0	0
Banks Pumping Plant (SWP)	2	0	1	0	1
Tracy Pumping Plant (CVP)	2	1	1	0	0

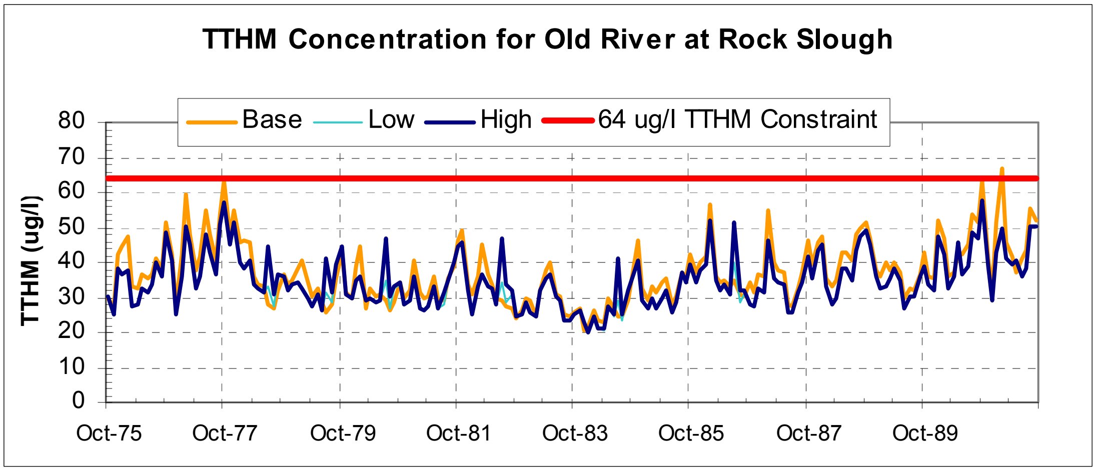

Figure 4.63: TTHM Concentration for Old River at Rock Slough.

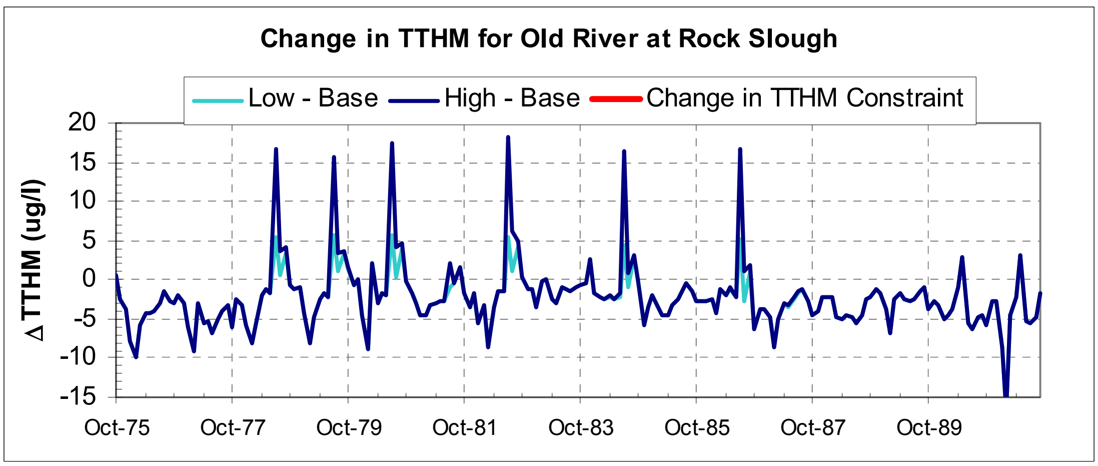

Figure 4.64: Change in TTHM for Old River at Rock Slough.

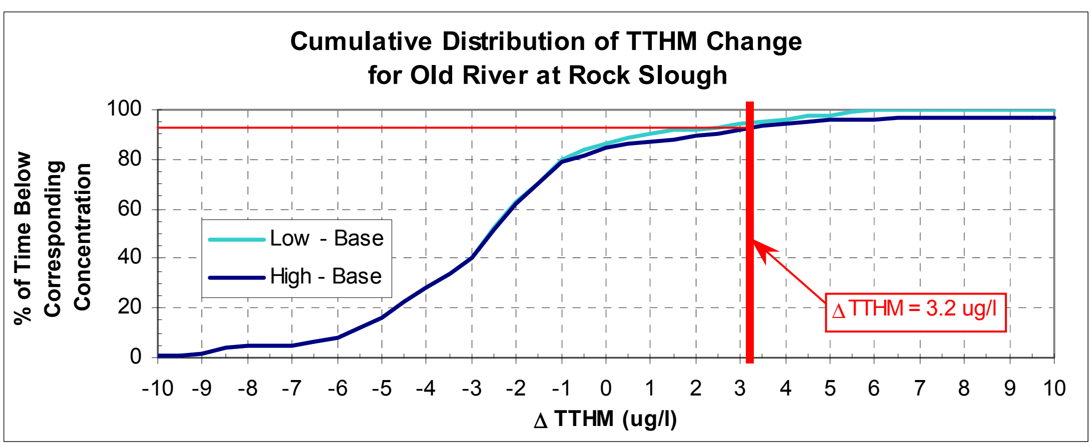

Figure 4.65: Cumulative Distribution of TTHM Change for Old River at Rock Slough.

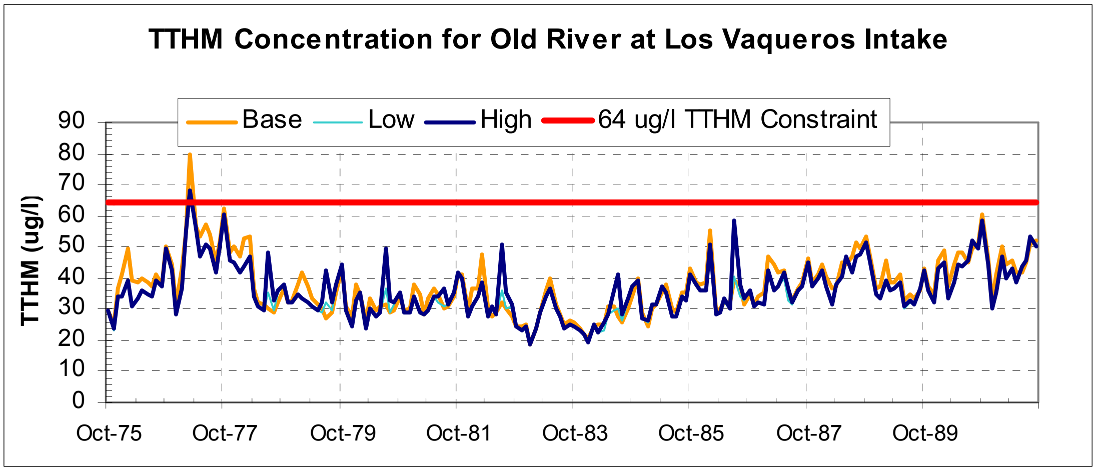

Figure 4.66: TTHM Concentration for Old River at Los Vaqueros Intake.

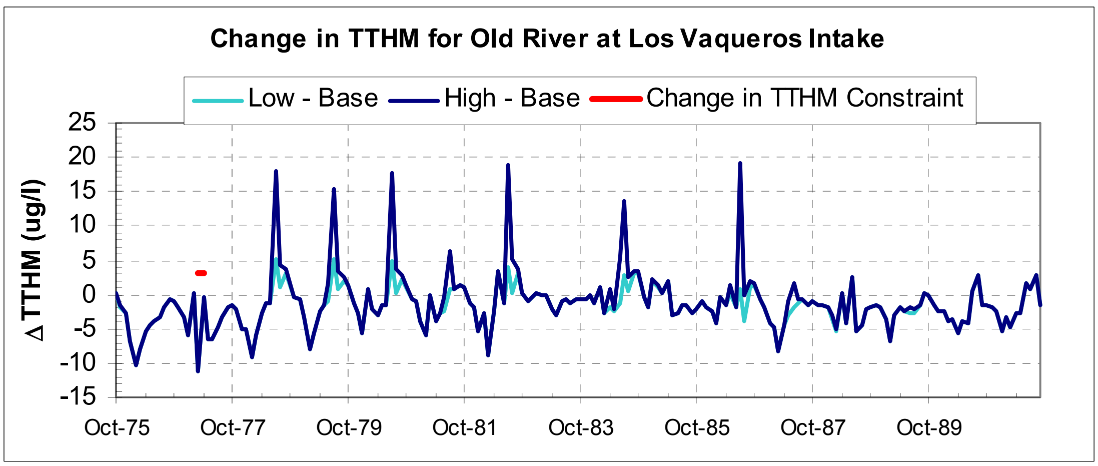

Figure 4.67: Change in TTHM for Old River at Los Vaqueros Intake.

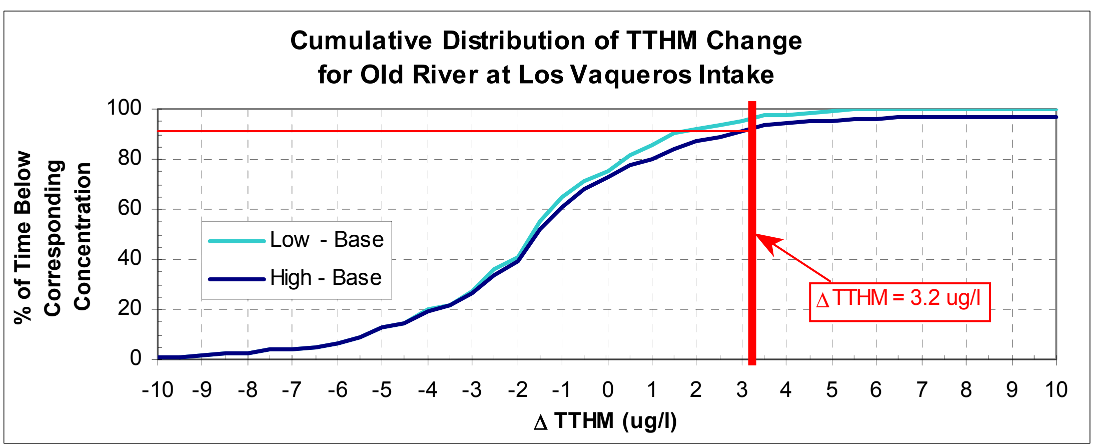

Figure 4.68: Cumulative Distribution of TTHM Change for Old River at Los Vaqueros Intake.

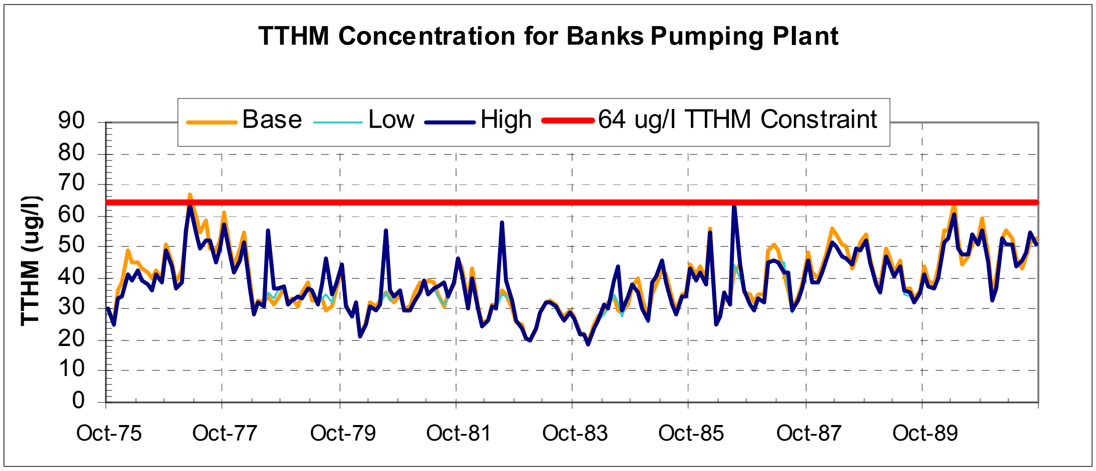

Figure 4.69: TTHM Concentration for Banks Pumping Plant.

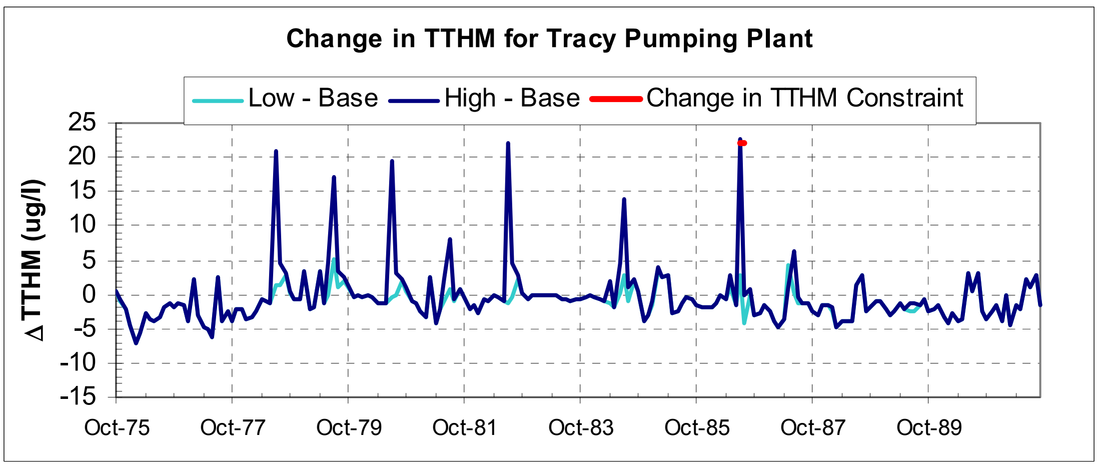

Figure 4.70: Change in TTHM for Banks Pumping Plant.

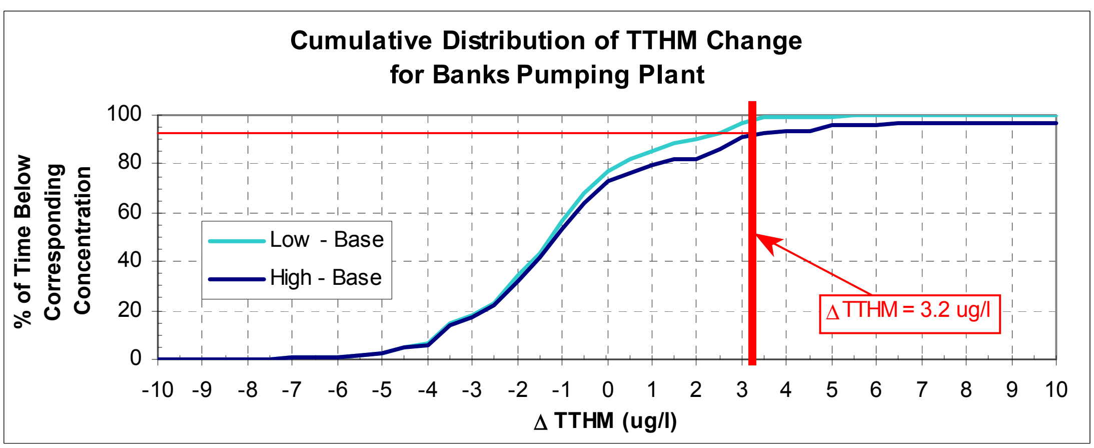

Figure 4.71: Cumulative Distribution of TTHM Change for Banks Pumping Plant.

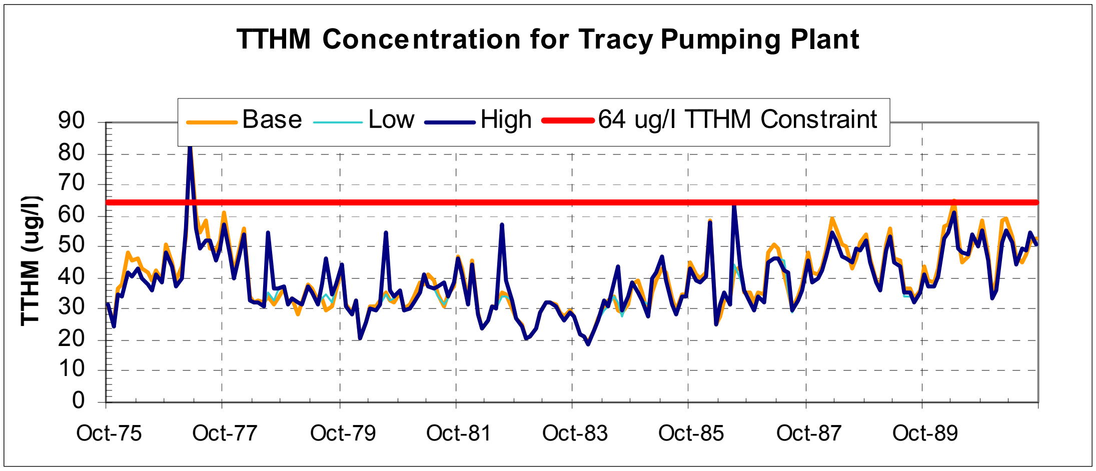

Figure 4.72: TTHM Concentration for Tracy Pumping Plant.

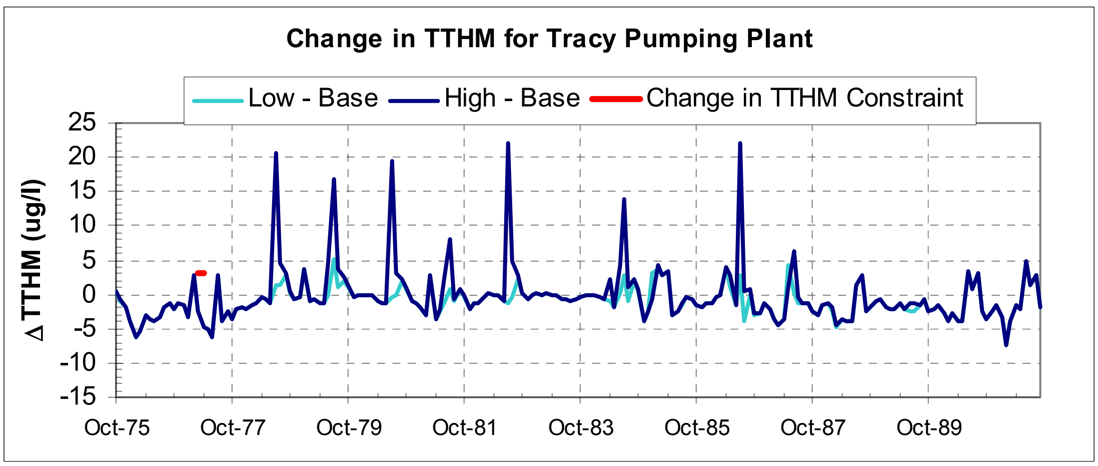

Figure 4.73: Change in TTHM for Tracy Pumping Plant.

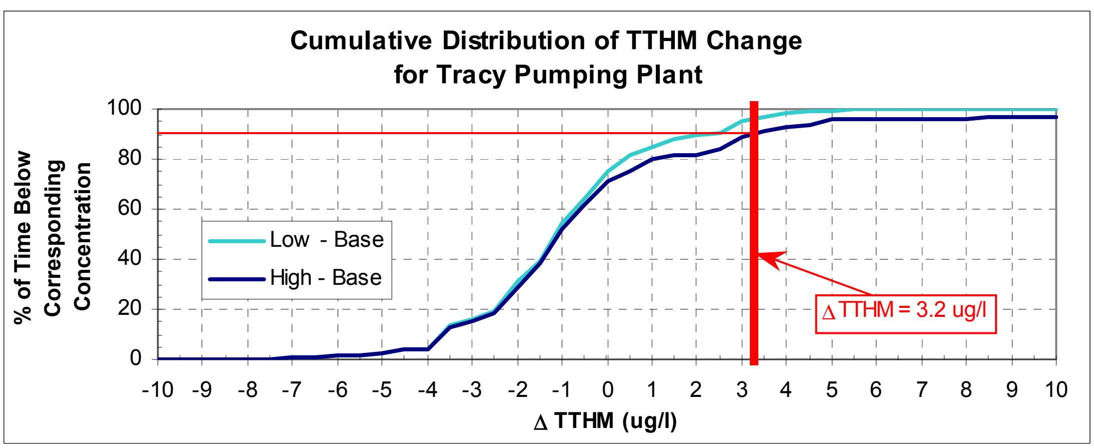

Figure 4.74: Cumulative Distribution of TTHM Change for Tracy Pumping Plant.

4.7 Bromate

According to the WQMP bromate formation is limited to 8 ug/l. For periods when the modeled base case exceeds this 8 ug/l constraint, the WQMP permitted a 5% increase above the constraint (0.4 ug/l) due to operation of the project.

Using EC and DOC discussed in Sections 4.1 and 4.3 above, bromate for all four urban intakes was calculated using (Hutton, 2001):

$$BRM = C_2 \times DOC^{0.31} \times Br^{0.73} \qquad \text{[Eqn. 11]}$$

where

BRM = bromate (ug/l),
C_2 = 9.6 when DOC < 4 mg/l,
C_2 = 9.2 when DOC ≥ 4 mg/l,
DOC = raw water dissolved organic carbon (mg/l) from DSM2, and
Br = raw water bromide (mg/l) from Equations 8 and 9.

The sensitivity of bromate formation potential to project operations is shown in Figures 4.76 - 4.87. Bromate formation is a function of both DOC and bromide concentration. The bromide concentration was calculated based on the EC results discussed in Section 4.1 using Equations 8, 9, and 10 (see Section 4.6). The two DOC bookends modeled were used to calculate two different bromate bookends. Time series plots of the monthly average bromate formation potential at the four intake locations are shown in Figures 4.76, 4.79, 4.82, and 4.85. The base case and alternative simulation bromate formation potentials frequently exceed the 8 ug/l level.

The maximum monthly average bromate concentrations for each of the bookend simulations is displayed in Table 4.21. The base case maximum monthly averaged bromate concentrations were higher than both alternative simulation concentrations for all four locations. Tracy had the highest maximum monthly bromate concentration for all three simulations.

Table 4.21: Maximum Monthly Averaged Bromate (ug/l).

Location	*Base*	*Low Bookend*	*High Bookend*
Old River at Rock Slough	11.67	11.51	11.51
Old River at Los Vaqueros Intake	10.50	10.10	10.10
Banks Pumping Plant (SWP)	11.47	11.30	11.30
Tracy Pumping Plant (CVP)	12.96	12.86	12.86

The WQMP constrained the operation of the project such that bromate concentrations should not exceed 8 ug/l, unless the modeled base case bromate already exceeds 8 ug/l (Hutton, 2001). When the base bromate concentration exceeded this constraint, an incremental constraint of 0.4 ug/l applies. When the base bromate concentration was less than 8 ug/l, the incremental increase was set-up such that the alternative bromate concentration would not exceed the 8 ug/l constraint. At these times the incremental constraint is simply the difference between 8 ug/l and the modeled base case, as is shown in Figure 4.75.

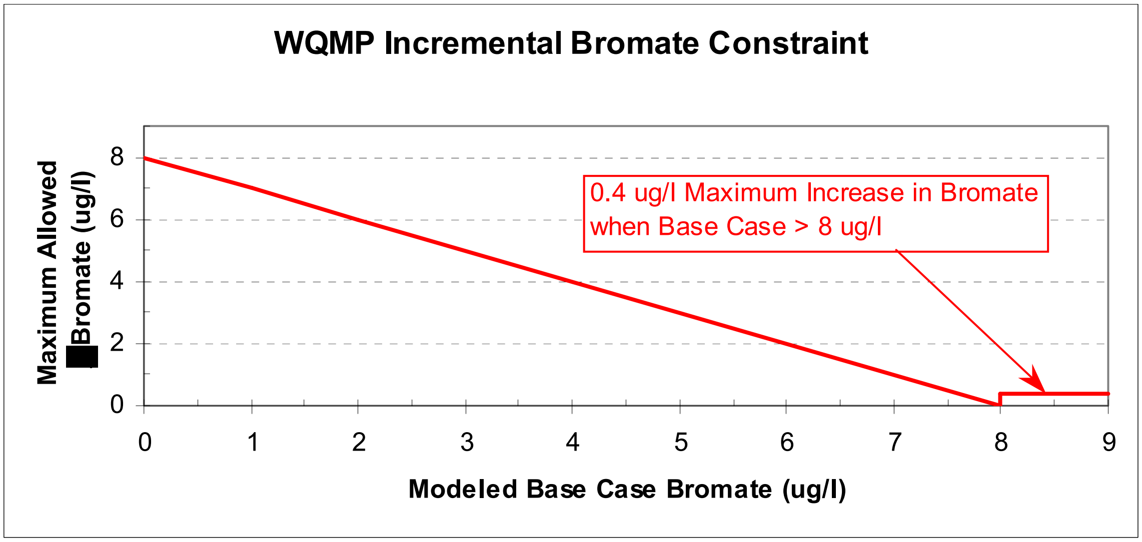

Figure 4.75: WQMP Incremental Bromate Constraint.

Time series plots illustrating the change in bromate formation (alternative - base) are shown in Figures 4.77, 4.80, 4.83, and 4.86. The incremental constraint discussed above is shown on each plot when it applies. The alternative simulation is in violation of this standard only when the change in bromate formation exceeds the constraint. Both the low- and high-bookend simulations violated the change in bromate formation constraint at Old River at Rock Slough and Old River at Los Vaqueros Intake in Oct. 1979. Both the low- and high-bookend simulations violated the change in bromate formation constraint two months, Oct. 1981 and Dec. 1988, at Banks and Tracy. The maximum difference between the alternative simulations and the base case generally decreased the further the output location was from the ocean boundary.

The maximum change in monthly averaged bromate formation for the two bookend simulations is displayed in Table 4.22. The largest increase in the monthly averaged bromate formation was at the Old River at Rock Slough location for both the low- and high-bookend simulations.

Table 4.22: Maximum Monthly Averaged Increase in Bromate (ug/l).

Location	*Low - Base*	*High - Base*
Old River at Rock Slough	1.35	1.39
Old River at Los Vaqueros Intake	1.16	1.19
Banks Pumping Plant (SWP)	0.84	0.86
Tracy Pumping Plant (CVP)	0.85	0.87

Typically the maximum monthly bromate concentrations occur in the high salinity periods (winter). Changes in land use made using the DICU model coupled with the winter time diversion of water from Delta channels to the island reservoirs resulted in lower maximum monthly averaged bromate concentrations at the urban intake locations when compared to the base case (see Table 4.21). However, the summer releases from the project islands resulted in increases in the monthly averaged bromate concentrations at the urban intakes (see Table 4.22).

Frequency histograms of the percent increase in bromate for the entire simulation period were used to create cumulative distribution functions (cdfs). These cdfs are shown in Figures 4.7.3, 4.7.6, 4.7.9, and 4.7.12. Although a change in bromate concentration of 0.4 ug/l is shown on each figure, the WQMP change in bromate formation constraint frequently is much higher than this amount. However, this value, 0.4 ug/l, represents 5% of the 8 ug/l standard and thus is used to illustrate how frequently the change in the bromate formation is equal to or greater than a 5% change. The percent of time that the change in bromate (alternative - base) is greater than this level is shown for each location in Table 4.23.

Table 4.23: Percent of Time that the Change in Bromate is Greater Than 0.4 ug/l.

Location	*%Exceedance Low - Base*	*%Exceedance High - Base*
Old River at Rock Slough	6.3	9.4
Old River at Los Vaqueros Intake	5.7	7.8
Banks Pumping Plant (SWP)	3.6	4.7
Tracy Pumping Plant (CVP)	3.6	4.7

The number of months, out of the 192 months simulated, exceeding the WQMP bromate constraints for both bookend simulations are shown below in Table 4.24. Though the simulated bromate concentration frequently exceeded 8 ug/l, it is the change in bromate constraint that measures the total number of violations of the WQMP. At the two locations closest to the ocean boundary, Old River at Rock Slough and Old River at Los Vaqueros Reservoir, the only violation of the change in bromate constraint occurred in Oct. 1979. Further south, the two violations occurred in Oct. 1981 and Dec. 1988.

Table 4.24: Number of Months of Exceedance of the WQMP Bromate Constraints.

	8 ug/l Bromate Constraint			**Change in Bromate Constraint**	
Location	***Base***	***Low***	***High***	***Low***	***High***
Old River at Rock Slough	46	39	39	1	1
Old River at Los Vaqueros Reservoir	28	25	25	1	1
Banks Pumping Plant (SWP)	24	21	21	2	2
Tracy Pumping Plant (CVP)	26	23	23	2	2

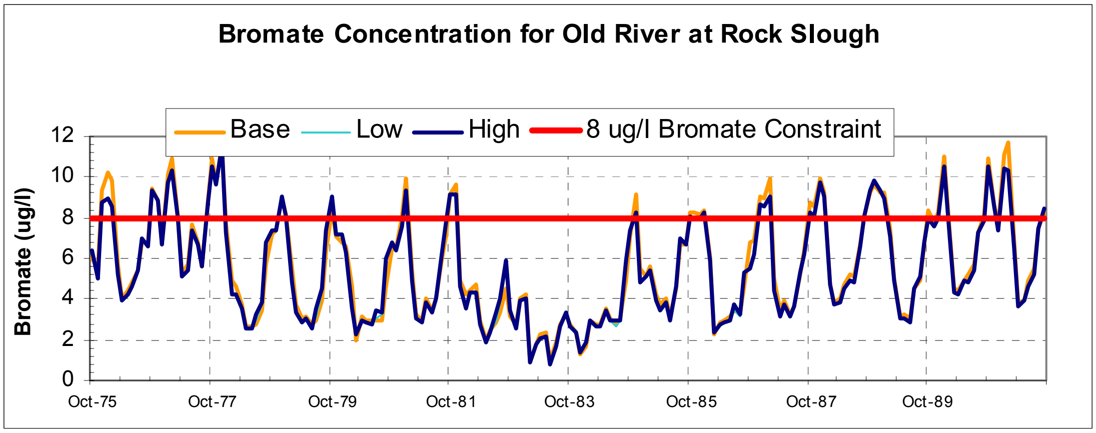

Figure 4.76: Bromate Concentration for Old River at Rock Slough.

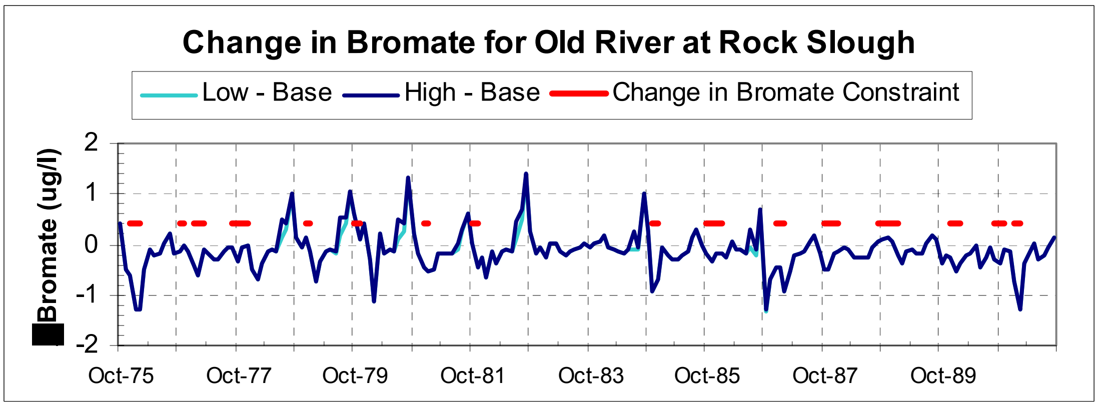

Figure 4.77: Change in Bromate for Old River at Rock Slough.

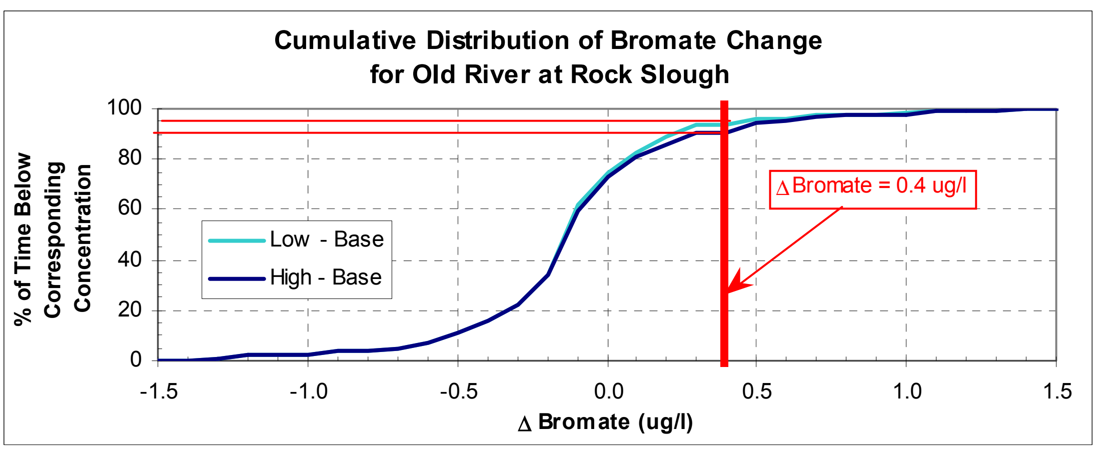

Figure 4.78: Cumulative Distribution of Bromate Change for Old River at Rock Slough.

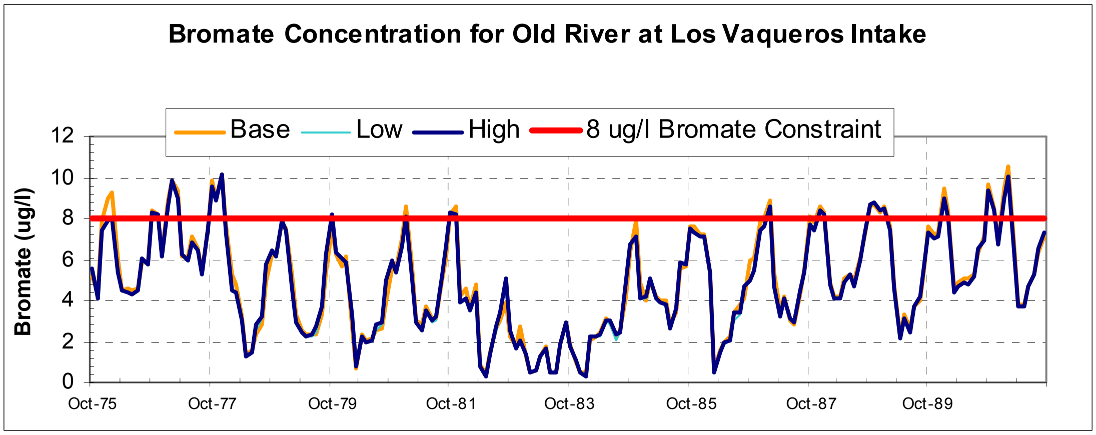

Figure 4.79: Bromate Concentration for Old River at Los Vaqueros Intake.

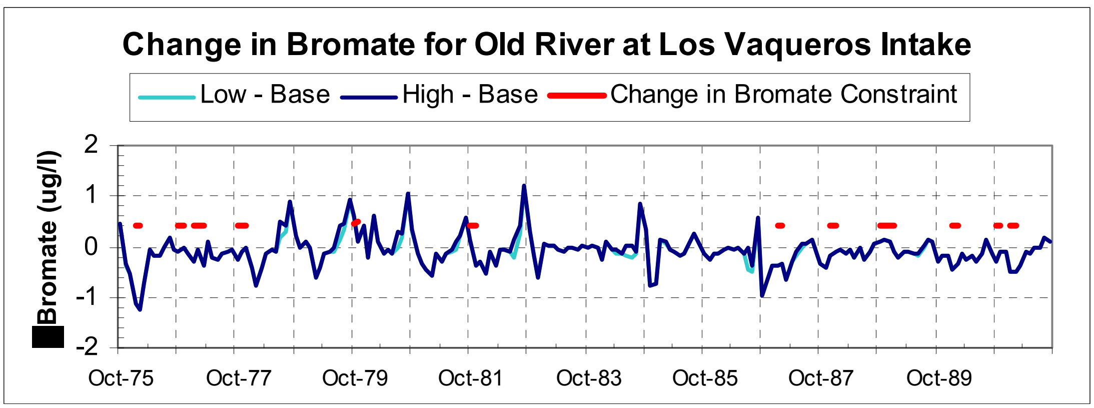

Figure 4.80: Change in Bromate for Old River at Los Vaqueros Intake.

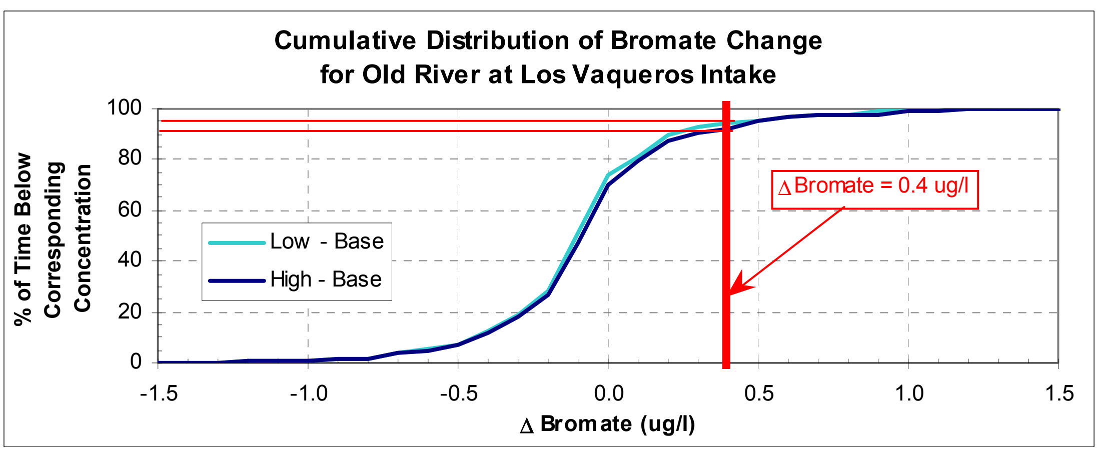

Figure 4.81: Cumulative Distribution of Bromate Change for Old River at Los Vaqueros Intake.

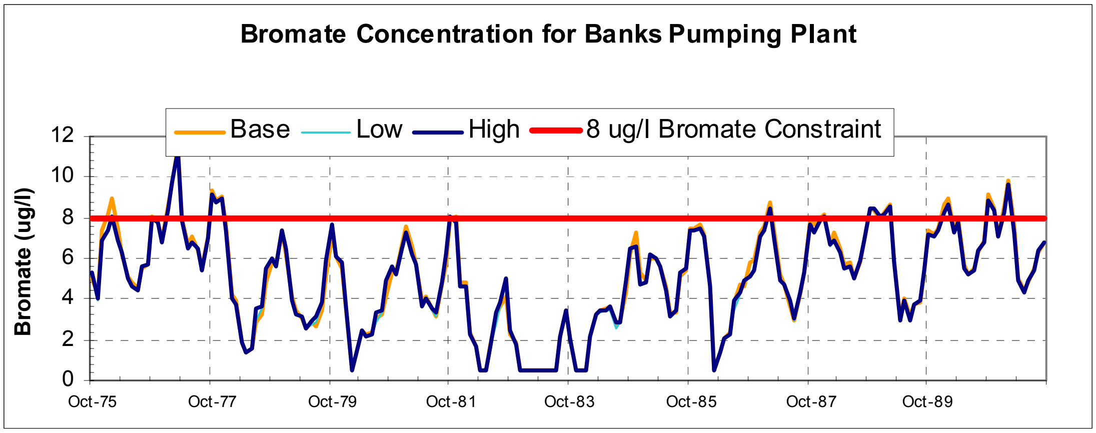

Figure 4.82: Bromate Concentration for Banks Pumping Plant.

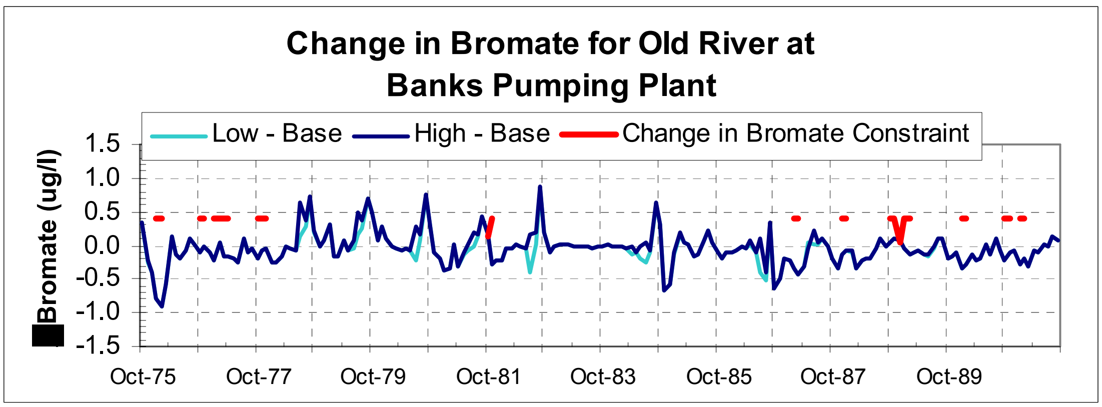

Figure 4.83: Change in Bromate for Banks Pumping Plant.

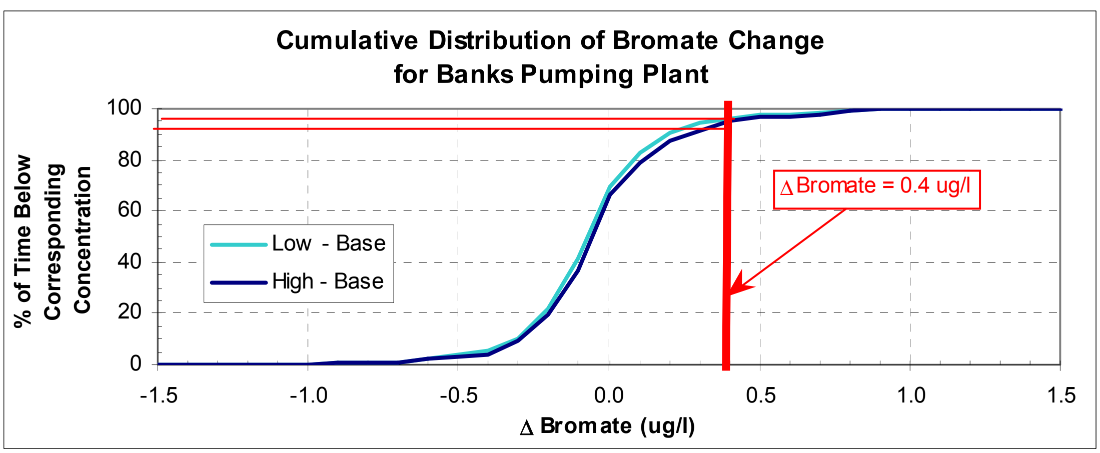

Figure 4.84: Cumulative Distribution of Bromate Change for Banks Pumping Plant.

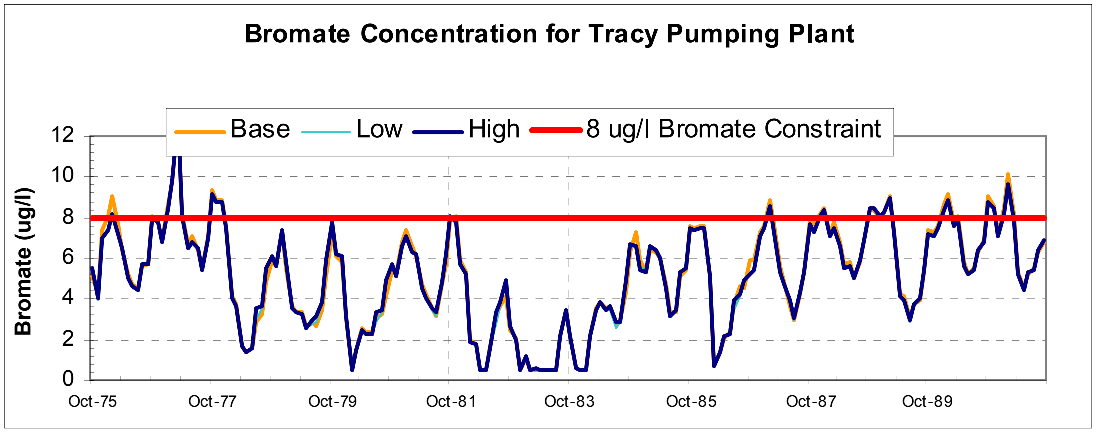

Figure 4.85: Bromate Concentration for Tracy Pumping Plant.

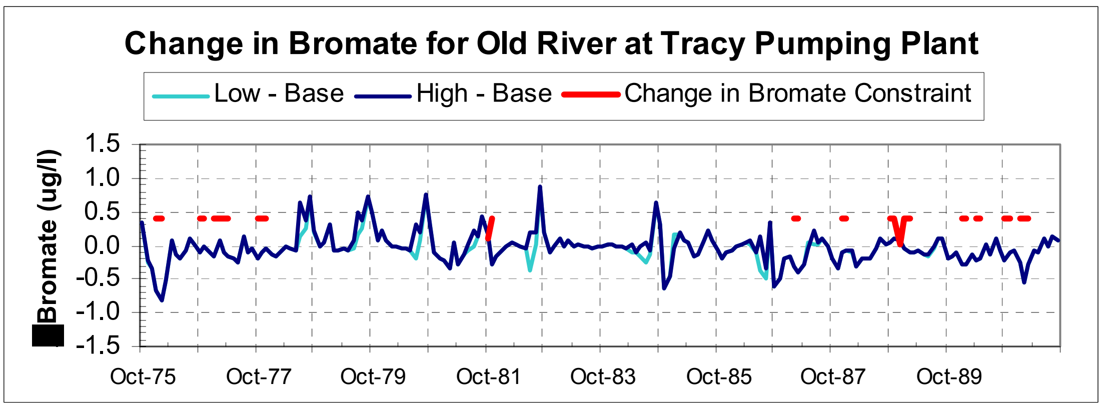

Figure 4.86: Change in Bromate for Tracy Pumping Plant.

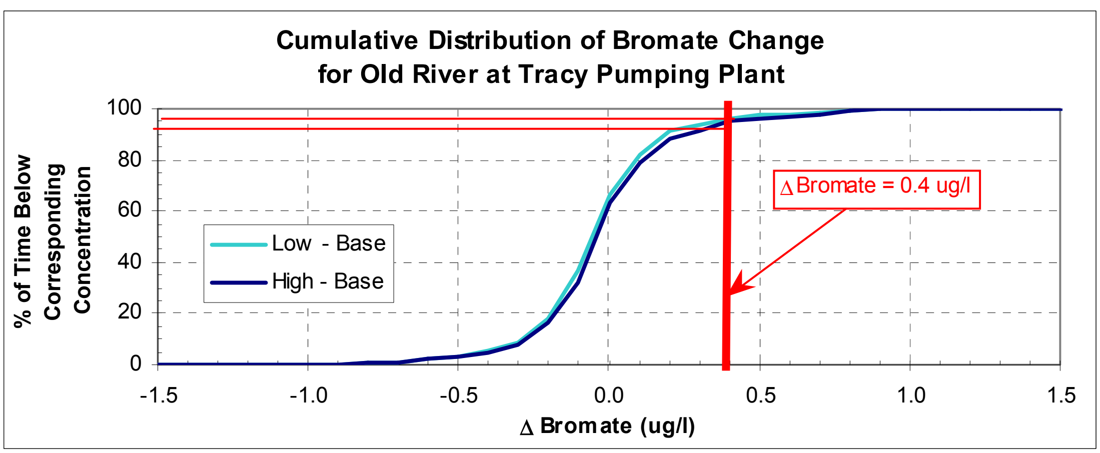

Figure 4.87: Cumulative Distribution of Bromate Change for Tracy Pumping Plant.

5 Conclusions

The results presented in this study focused primarily on comparing DSM2-QUAL results to the WQMP standards for chloride, DOC, TTHM, and bromate. DSM2-QUAL was modified to account for increases in DOC due to storage. There was no standard for UVA, but the results were shown above since they are used to calculate TTHM. The WQMP constraints apply at any of the urban water supply intakes, thus results were presented for the following locations: Old River at Rock Slough, Old River at the Los Vaqueros Reservoir, the Banks Pumping Plant (SWP), and the Tracy Pumping Plant (CVP) intakes.

A summary of the results for each constituent is presented below:

Chloride

- WQMP Constraints:
  Change in Chloride ≤ 10 mg/l, and
  Chloride (w/ Project) ≤ 225 mg/l.

- The base and alternative simulations exceeded 225 mg/l at the Old River at Rock Slough and Central Valley Project intakes. This constraint was not exceeded at the Old River at Los Vaqueros Reservoir intake and Banks Pumping Plant.

- The change in chloride due to operation of the project exceeded 10 mg/l at all four intake locations with the largest violation occurring at Rock Slough 5.7% of the time.

- The percent of time that change in chloride exceeded 10 mg/l ranged between 4 to 6% for the different intake locations.

Long-Term Chloride

- WQMP Constraint:
  Change in Long-Term Chloride Mass Loading ≤ 5%.

- The operation of the project exceeded the WQMP 5% long-term increase constraint between 0 to 9% of the time for the three urban intakes.[20] The greatest violation occurred at Rock Slough with 14 months exceeding 5%.

- The long-term chloride mass loading ranged between 0.7 to 2 thousand metric-tons/month at Rock Slough, 15 to 28 thousand metric tons/month at Banks, and 11 to 23 thousand metric tons/month at Tracy for both the base and alternative simulations.

[20] Old River at Los Vaqueros Reservoir was not calculated because the operations provided by CALSIM II do not separate the CCWD diversions between Rock Slough and Los Vaqueros.

DOC

- WQMP Constraint:
  Change in DOC ≤ 1 mg/l.[21]

- The low-bookend island release DOC quality ranged from 6 to 10 mg/l. The high-bookend island releases ranged from 13 to 22 mg/l.

- The base and both bookend alternative simulations exceeded 4 mg/l at all four intake locations.

- The change in DOC was greater than 1 mg/l at all four intake locations for high-bookend simulations. The change in DOC was greater than 1 mg/l at Banks and Tracy for the low-bookend simulations.

- The percent of time that change in DOC exceeded 1 mg/l ranged between 0 to 4% for the different intake locations.

Long-Term DOC

- WQMP Constraint:
  Change in Long-Term DOC Mass Loading ≤ 5%.

- The Banks Pumping Plant exceeded the WQMP 5% long-term increase constraint 0 months for the low-bookend and 78 months for the high-bookend. The Old River at Rock Slough intake exceeded this constraint for only 12 months for the high-bookend simulation.

- The operation of the project exceeded the WQMP 5% long-term increase constraint 0% of the time for the three urban intakes for the low-bookend simulation.[22] The WQMP 5% long-term increase constraint was exceeded 8 to 50% of the time for the high-bookend simulation.

- The long-term DOC mass loading ranged between 0.04 to 0.065 thousand metric-tons/month at Rock Slough, 0.5 to 1.9 thousand metric tons/month at Banks, and 0.7 to 1.2 thousand metric tons/month at Tracy for both the base and both bookend simulations.

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[21] The ΔDOC constraint was between 0 and 1 mg/l depending on the modeled base case DOC concentration (see Hutton, 2001).

[22] Old River at Los Vaqueros Reservoir was not calculated because the hydrodynamics provided by CALSIM II do not separate the CCWD diversions between Rock Slough and Los Vaqueros.

TTHM

- WQMP Constraint:
  Change in TTHM ≤ 3.2 ug/l.[23]

- The base and both bookend alternative simulations exceeded 64 ug/l at the Old River at Los Vaqueros Reservoir Intake and Tracy. The Banks and Tracy Pumping Plants exceeded the 64 ug/l concentration level for the base case and high-bookend, however, the high-bookend simulation did not increase the TTHM concentration at this time. Old River at Rock Slough did not exceed this concentration for any of the simulations.

- The percent of time that the change in TTHM was greater than 3.2 ug/l due to operation of the project ranged between 2 to 5% of the time for the different intake locations for the low-bookend simulation. Similarly, TTHM increased 7.7 to 10% of the time for the high-bookend simulation.

- The change in TTHM constraint was violated only once for the high-bookend simulation at Banks. The rest of the time that the change in TTHM was greater than 3.2 ug/l, the base case was less than 64 ug/l and the alternative did not exceed 64 ug/l.

Bromate

- WQMP Constraint:
  Change in Bromate ≤ 0.4 ug/l.[24]

- The base and both bookend alternative simulations exceeded 8 ug/l at all four intake locations. Rock Slough exceeded this concentration 39 months for both the low- and high-bookend simulations; compared to the 46 months the base case exceeded 8 ug/l at Rock Slough.

- The percent of time that the change in bromate was greater than 0.4 ug/l ranged around 6% at Old River at Rock Slough and Old River at Los Vaqueros for the low-bookend. This percentage increased to range between 8 and 9% for the same locations for the high-bookend. However, only one month did these increases result in a violation of the WQMP constraint. The rest of the time that the change in bromate was greater than 0.4 ug/l, the base case was less than 8 ug/l and the alternative did not exceed 8 ug/l.

- The percent of time that the change in bromate was greater than 0.4 ug/l at Banks and Tracy was less for both bookend simulations than for the other two locations, however, a total of two months these increases resulted in violations of the WQMP constraint.

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[23] The ΔTTHM constraint permitted any increase in TTHM when the base case was less than 64 ug/l, otherwise it limited the ΔTTHM to 5% of 64 ug/l (Hutton, 2001).

[24] The ΔBromate constraint permitted any increase in Bromate when the base case was less than 8 ug/l, otherwise it limited the ΔBromate to 5% of 8 ug/l (Hutton, 2001).

Over the course of the 16-year study, there was a violation of each water quality constraint at least one of the locations for the high-bookend simulations. The low-bookend simulations met the long-term DOC and TTHM constraints at all four locations, however there were violations at some of the locations for all of the other water quality constraints. The most significant violations of the WQMP constraints involved DOC. The Old River at Rock Slough was the only location that did not have a violation in the low-bookend. Out of the eight major release periods, the two Old River locations violated the high-bookend WQMP constraints 6 times, and then the Banks Pumping Plant (SWP) and Tracy Pumping Plant (CVP) violated the WQMP constraints 7 times.

There are chloride and bromate violations in the alternative simulations. Although these violations are not directly related to the releases or diversions (meaning they do not always occur during a project release or diversion), they represent a cumulative impact resulting from the re-operation of the entire system in CALSIM.

It is important to note that all of the results presented in this report were based on monthly averages. The WQMP actually applies to 14-day running averages. However, the process of averaging water quality results on a monthly basis tended to smooth out peaks in the results.

The modifications to QUAL did not account for increases in stored DOC due to primary productivity or due to seepage into the reservoirs from the neighboring channels. Robert Duvall of DWR-ISI is conducting work to study the impact of primary productivity.

The violations of the WQMP incremental standards could be minimized by implementing changes in the operation of the project (such as by designing additional operating constraints for CALSIM II to use while modeling the project diversions and releases). Previous DSM2-CALSIM II Delta wetlands studies have shown larger numbers (and magnitudes) of WQMP violations (Mierzwa, 2001). The principle differences between this and previous DSM2 studies are in the CALSIM II operations. One suggested approach to implementing changes in the operation of the project would be to decrease the magnitude of releases from the project islands, but extend the duration of these releases such that a similar volume of water is released.

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ISI Water Quality Studies for the In-Delta Storage Program
DWR Delta Modeling Work Plan
May 2001 Revision #2

CALFED stakeholders were briefed on the proposed work plan on February 13, 2001 through the Drinking Water Quality Operations Workgroup. This is a revision to the March 19, 2001 draft work plan.

I. DSM2 STUDIES

1. Evaluate Delta Wetlands 2000 Revised EIR/S Operations Studies

Purpose: To evaluate water quality impacts of operating DW Project according to assumptions in EIR/S. Water quality impacts will be measured against the objectives outlined in D-1641, D-1643 and the DW Water Quality Management Plan (WQMP).

Description: David Forkel provided us with Jones and Stokes' base and plan operations study results in Excel format. The base study represents the No Action Alternative and the plan study represents unlimited South of Delta demand (Scenario #1). Ten DSM2 simulations of the period 1976-91 will be conducted, employing the EIR/S hydrology and operations and bookend water quality assumptions:

Study 1: Base Case (No Action) -- EC
Study 2: Base Case (No Action) -- DOC
Study 3: Base Case (No Action) -- UV-254
Study 4: DW Operations -- EC
Study 5: DW Operations (6 mg/L DOC release) -- DOC
Study 6: DW Operations (15 mg/L DOC release) -- DOC
Study 7: DW Operations (30 mg/L DOC release) -- DOC
Study 8: DW Operations (6 mg/L DOC release) -- UV-254
Study 9: DW Operations (15 mg/L DOC release) -- UV-254
Study 10: DW Operations (30 mg/L DOC release) -- UV-254

Duration: 1 month
Expected Start Date: March 2001
Expected End Date: April 2001

Product: A memorandum report will be prepared summarizing study assumptions and results.

2. Evaluate In-Delta Storage Alternatives with Reconnaissance-Level Water Quality Rules

Purpose: To evaluate water quality impacts of In-Delta Storage alternatives and identify any violations of WQMP.

Description: Several DSM2 simulations will be conducted, employing Delta hydrology and operations provided by CALSIM studies. DSM2 simulations will utilize daily changing Delta hydrology provided by CALSIM and MAY utilize a non-repeating tide (see Task IV-1). DSM2 simulations will utilize an IDS release water quality module developed in consultation with MWQI staff (see Task IV-2). CALSIM simulations will utilize WQMP constraints developed in Task VI-1 and IDS operations rules developed in Task VI-2. Some iteration in development of IDS operations rules will likely be necessary.

Duration: 6 months
Expected Start Date: July 2001
Expected End Date: January 2002

Product: A draft memorandum report will be prepared summarizing study assumptions and results.

3. Finalize Analysis of In-Delta Storage Alternatives

Purpose: To refine the evaluation of water quality impacts associated with In-Delta Storage alternatives.

Description: DSM2 simulations conducted in Task II-2 will be refined utilizing the most current CALSIM studies. CALSIM operations studies will utilize ANNs trained to predict Delta organic concentrations (see Task V-3).

Duration: 3 months
Expected Start Date: January 2002
Expected End Date: April 2002

Product: A memorandum report will be prepared summarizing study assumptions and results.

II. DSM2 TOOL AND DATA DEVELOPMENT

1. Develop 16-Year Planning Study Setup With Daily Varying Hydrology/Operations and Non-Repeating Tide

Purpose: To conduct DSM2 water quality planning studies consistent with CALSIM output.

Description: DSM2 planning studies utilize CALSIM hydrology and operations as input. In the past, this input has been provided on a monthly time step. As part of the IDS project, CALSIM will soon be providing Delta hydrology and operations on a daily time step. It is anticipated that DSM2 will provide more meaningful hydrodynamic and water quality responses to daily changing hydrology and operations. Several modifications must be made to the DSM2 planning study setup to accommodate the additional CALSIM input data. The DSM2 planning study setup will also be modified to accommodate a non-repeating tide. In the past, DSM2 planning studies have utilized a 25-hour repeating tide. While such an approach is computationally advantageous, it does not allow for the evaluation of the spring-neap cycle. The DSM2 non-repeating tide will reflect historical conditions. For example, a 16-year planning study (1976-91) will utilize the tidal stage as observed at Martinez for every computational time step (i.e. 15 minutes) of the simulation period.

Duration: 4 months
Expected Start Date: March 2001
Expected End Date: July 2001

Product: DSM2 user documentation will be updated.

2. Develop Reservoir Island Release Water Quality Module and Implement in DSM2

Purpose: To simulate water quality changes in In-Delta Storage reservoirs in accordance with best available science.

Description: MWQI consultants and staff will develop a conceptual model and mathematical relationships to describe changes in water quality IDS reservoirs based upon experimental data (SMARTS). Explanatory variables may include diversion quality, residence time, season, water level, and soil characteristics. Delta Modeling staff will collaborate with MWQI staff to develop a water balance module that incorporates the concepts and mathematical relationships developed by MWQI. Delta Modeling staff will develop an appropriate linkage of this module to DSM2. The module could be utilized as a pre-processor or could be dynamically linked to DSM2.

Duration: 4 months
Expected Start Date: March 2001
Expected End Date: July 2001

Product: MWQI staff will prepare a memorandum report, describing model algorithm and assumptions. Delta Modeling staff will update DSM2 user documentation as required.

3. Data Development

Purpose: A variety of data development subtasks must be completed to evaluate IDS on a daily time step with DSM2.

- Subtask 3-1 Develop a Data Input Editor -- A tool will be developed to assist in Delta hydrodynamics and water quality time series data visualization, manipulation, and quality control.

  Duration: 3 months
  Expected Start Date: January 2001
  Expected End Date: April 2001

  Product: DSM2 user documentation will be updated.

- Subtasks 3-2 Salinity Regression Relationships -- IDS will be operated to meet salinity D-1641 standards or WQMP constraints for EC, chloride, and bromide. CALSIM and DSM2 simulations will be conducted in EC. Model output will be translated into chloride and bromide as necessary to compare with standards and constraints.

  Duration: 6 months
  Expected Start Date: July 2001
  Expected End Date: January 2002

  Product: Results will be provided to CALSIM team.

- Subtask 3-3 Real Tide Stage – A 16-year time series of observed tidal stage at Martinez will be developed to use as the downstream boundary condition for DSM2 planning studies. Data will be developed at 15-minute intervals. Data fill-in procedures will be utilized to augment observed data.

  Duration: 3 months
  Expected Start Date: March 2001
  Expected End Date: June 2001

  Product: A new data set will be developed and made available through the IEP web page for public review. This data set would be available for future interagency model calibrations and peer reviews.

- Subtask 3-4 Water Temperature Daily Time Series – Predicted TTHM formation at urban intakes is a function of several variables, including water temperature. One annual pattern of monthly averages is assumed to represent all urban intakes. Create a smoothed daily time series from the monthly averages.

- Subtask 3-5 Geometry Changes for Alternative 3 – Make necessary geometry changes in DSM2 input files to represent IDS Alternative 3, which assumes Victoria Island as an IDS reservoir.

- Task 3-6 Develop Habitat Island Assumptions – Implement appropriate assumptions for island diversion volumes, return volumes, and return water quality for habitat islands. Replace assumptions currently in the DICU model for agricultural land use.

- Task 3-7 UVA Conservation – Demonstrate that UVA can be modeled as a conservative constituent. DWR's Water Quality Assessment staff have been asked to conduct a dilution test to demonstrate.

- Task 3-8 Develop Appropriate Ratios between TOC and DOC. DWR's Water Quality Assessment staff has indicted that the DOC:TOC ratio is complex and may vary temporally and spatially. Assumed ratios may need to account for seasonal variation. If spatial variation is significant, TOC may need to be simulated directly (instead of DOC).

III. CALSIM ARTIFICIAL NEURAL NETWORK DEVELOPMENT AND ENHANCEMENTS

1. Enhance Existing CALSIM ANN: Phase 1

Purpose: To improve the predictive ability of the existing CALSIM2 ANN.

Description: The CALSIM salinity ANN will be re-trained with data generated by the most recent calibration of DSM2 (2000 IEP PWT calibration). The ANN approach will be tested for stability under a variety of extreme conditions, including future demand and level of development scenarios.

Duration: 2 months
Expected Start Date: February 2001
Expected End Date: April 2001

Product: This task will result in an improved CALSIM ANN module.

2. Enhance Existing CALSIM ANN: Phase 2

Purpose: To add features necessary for evaluating salinity impacts of In-Delta Storage alternatives with daily changing hydrology and non-repeating tide over a 16-year planning period.

Description: The CALSIM salinity ANN input structure will be modified to reflect potential IDS facilities and operations. The ANN will be trained on daily-changing hydrology and operations, and will provide daily average salinity output at current D-1641 locations as well as at IDS diversion points and representative urban intakes specified in the WQMP.

Duration: 2 months
Expected Start Date: April 2001

Expected End Date: June 2001

Product: This task will result in a CALSIM ANN module that will insure that the IDS meets salinity objectives outlined in D-1641 and in the WQMP.

3. Develop and Implement New CALSIM ANNs for DOC and UVA

Purpose: To develop an efficient CALSIM module that insures that IDS meets organic/DBP objectives outlined in the WQMP.

Description: CALSIM2 will require information on how to operate the In-Delta Storage Project while meeting the WQMP objectives. The operating rules must specify when and how much water should be diverted into storage or released from storage. CALSIM2 is currently provided salinity-based water quality conditions in the Delta through an Artificial Neural Network (ANN) flow-salinity routine. The existing ANN is trained on DSM2 salinity transport simulations. This project will develop new ANNs that provide CALSIM2 with information on organic-based water quality conditions. These new ANNs will be trained on DSM2 simulations of dissolved organic carbon (DOC) and ultraviolet absorbance (UV-254). It is anticipated that the structure of the organic ANNs will be significantly different from the salinity ANN.

Duration: 7 months
Expected Start Date: June 2001
Expected End Date: January 2002

Product: This task will result in a CALSIM ANN module that will insure that the IDS meets organic water quality objectives outlined in the WQMP.

IV. CALSIM WATER QUALITY RULES DEVELOPMENT

1. Consult CALSIM Team in Developing Water Quality Constraints

Purpose: To develop CALSIM linear programming constraints that adequately represent the WQMP.

Description: Consult with CALSIM Team to interpret the Delta Wetlands WQMP. Assist in identifying key water quality constraints and formulating representative linear programming constraints.

Duration: <1 month
Expected Start Date: March 2001
Expected End Date: July 2001

Product: The CALSIM team will develop LP constraints that appropriately represent the WQMP.

2-4. Develop Reconnaissance-Level Water Quality Rules for In-Delta Storage Operations

Purpose: To develop simplified CALSIM operating rules that insure that the In-Delta Storage Project meets organic/DBP objectives outlined in the WQMP.

Description: CALSIM2 will require information on how to operate the In-Delta Storage Project while meeting the WQMP objectives. The operating rules must specify when and how much water should be diverted into storage or released from storage. CALSIM2 is currently provided salinity-based water quality conditions in the Delta through an Artificial Neural Network (ANN) flow-salinity routine. Our intent is to develop new ANNs that provide CALSIM2 with information on organic-based water quality conditions. However, our experience with ANN development indicates that such a project may extend beyond the timeframe of the Program. Therefore, we intend to develop simplified operating rules in parallel with ANN development. Simplified operating rules will be developed through a trial-and-error DSM2 simulation approach. The following subtasks are identified:

1. Diversion Rules
2. Diversion Water Quality Specification
3. Release Rules

Duration: 4 months
Expected Start Date: March 2001
Expected End Date: July 2001

Product: A draft memorandum report will be prepared summarizing study assumptions and results.

5. Develop New CALSIM Cross Delta Flow Relationships

Purpose: To develop new CALSIM relationships that estimate flows through the Delta Cross Channel and Georgiana Slough.

Description: The existing relationship, which predicts Cross Delta flow as a function of Sacramento River flow, is inadequate when utilized on a daily time step. A new relationship will be developed with DSM2 data. The new relationships will be a function of Sacramento River flow, Mokelumne and Cosumnes Rivers flow, and Yolo Bypass flow.

Duration: <1 month
Expected Start Date: May 2001
Expected End Date: June 2001

Product: Multivariate regression equations will be provided to CALSIM team. A draft memorandum will be prepared summarizing study assumptions and results.

Memorandum

Date: December 3, 2001

To: Tara Smith

From: Jamie Anderson
Delta Modeling
Office of SWP Planning
Department of Water Resources

Subject: DSM2 Fingerprinting Simulation for the In-Delta Storage Investigations

This memo documents a DSM2 fingerprinting study conducted as part of the In-Delta Storage investigations. As part of the analysis of the impacts of the In-Delta Storage alternatives on water quality concentrations in the Delta, an improved understanding of source and flow contributions throughout the Delta was desired. Thus, a DSM2 fingerprinting study was conducted to determine the relative contributions of the system inflows to total flow and water quality concentrations at selected Delta locations, including the original proposed Delta Wetlands project intake and release locations.

Relative flow contributions from six sources were examined for the time period March 1991 through September 1998. The six flow sources examined were the Sacramento River, San Joaquin River, Martinez, eastside streams, agricultural drains, and the Yolo Bypass. Simulation results are detailed in this memo for eight selected locations. Four of the analysis locations correspond to export locations: Old River Rock Slough, Old River at Highway 4 (Los Vaqueros), Clifton Court Forebay, and the Delta Mendota Canal intake. Four additional analysis locations correspond to the intakes for the original Delta Wetlands project: Webb Tract Intakes 1 and 2, and Bacon Island Intakes 1 and 2.

Since high DOC concentrations are typically an issue of concern during wet months, the finger printing results were analyzed on a monthly basis. Since DOC concentrations tend to increase after major rainfall events, monthly flow contributions for wet and critical years were analyzed separately. For all eight locations, the Sacramento River provided the major flow contribution during winters of critical years (56%-95%), and San Joaquin River flow contributions were highest during January of wet years (15%-62%). During winters of wet years San Joaquin River flow contributions increased at all locations, and in fact provided the majority of the flow at both the Clifton Court Intake and the Delta Mendota Canal. As might be expected based on their relative locations, San Joaquin River flow contributions were higher for the Bacon Island intake locations than for the Webb Tract locations in both wet and critical years. Agricultural drainage flow contributions were less than 6% at all locations except during January of wet years when the flow contributions increased up to 14%. Agricultural drainage concentrations were typically higher at the southern locations (the four export locations and at Bacon Island Intake 2) than at the more northern locations (the Webb Tract intakes and Bacon Island Intake 1).

Finger printing results for flow contributions for the winter months during wet and critical years were utilized to estimate ranges of DOC concentrations at the four export locations and at the four original Delta Wetlands intake locations. During December and January of critical years the highest average maximum DOC concentrations throughout the system were estimated when DOC concentrations in the Sacramento River were high since the Sacramento River provided the major flow contribution during those time periods. During December and January of critical years, varying the DOC concentrations in the San Joaquin River and in agricultural drainage produced minor changes in estimated DOC concentrations except at Clifton Court and the Delta Mendota Canal. This is due to the fact that the Clifton Court and Delta Mendota Canal sites were the only sites examined where the San Joaquin River made significant flow contributions during critical years. Additionally, flow contributions from agricultural drainage were less than 7% at all sites during critical years. In winters of wet years, the highest estimated DOC concentrations were associated with high DOC concentrations for the major flow contributor at each location (the Sacramento River for the In-Delta Storage and Old River intakes and the San Joaquin River for Clifton Court and the Delta Mendota Canal). In January of wet years, flow contributions from agricultural drainage increased to levels that produced the highest estimated DOC concentrations at all locations when the DOC concentrations of the agricultural drainage were high. Thus, a very high source DOC concentration can have a large impact on the total estimated DOC at a given location even if the flow contribution from that source is relatively minor.

In summary, DSM2 finger printing simulations were conducted to analyze the relative flow contributions of six sources throughout the Delta. Simulation results were examined at four export and the four original Delta Wetlands intake locations. Relative flow contributions from the six sources were analyzed as time series over the entire simulation period and on a monthly basis for both wet and critical years. The simulated relative flow contributions were then utilized to conduct a sensitivity analysis of estimated DOC concentrations at the eight study sites. Typically estimated DOC concentrations were highest when there were high DOC levels in the flow source that provided the major flow contribution for winters of both critical and wet years. However, during January of wet years, flow contributions from agricultural drainage increased to levels high enough that the highest estimated DOC concentrations were produced when the DOC concentrations of the agricultural drainage were high. The DSM2 finger printing technique provides a useful tool for sensitivity analysis of boundary condition effects on water quality at selected Delta locations.

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Introduction

For the In-Delta Storage project, DSM2 is being utilized to simulate dissolved organic carbon (DOC) concentrations for both base line and proposed operational alternatives. The proposed Delta Wetlands operational alternatives involve flooding four Delta islands (Figure 2). It is proposed to flood Webb Tract and Bacon Island during high flow periods. These islands would be utilized as in-Delta reservoirs that would provide storage for the water for use during lower flow periods. Additionally it is proposed to create shallow water habitat in the Delta by flooding Bouldin Island and Holland Tract. For this study, the original proposed Delta Wetlands intake and release locations were used (Figure 2). Later modifications to the proposed intake and release locations were not incorporated into this study. As part of the analysis of the impacts of the In-Delta Storage alternatives on water quality concentrations in the Delta, an improved understanding of source contributions throughout the Delta was desired. Thus, a DSM2 fingerprinting study was conducted to determine the relative contributions of the system inflows to total flow and water quality concentrations at selected Delta locations.

For this finger printing study, the DSM2 hydrodynamics and water quality validation simulations conducted by the DWR Delta Modeling Section were utilized as a base case. The validation simulation was conducted for the time period March 1991 through September 1998. The hydrology utilized in the validation study included a time varying representation of the tidal boundary at Martinez. For the validation, simulated water quality constituent concentrations were compared to observed concentrations. The validation studies are described in more detail in Nader-Tehrani (2001) and Pandey (2001).

For the validation finger printing study, relative flow contributions from six sources were examined. The six sources were the Sacramento River, San Joaquin River, Martinez, eastside streams, agricultural drains, and the Yolo Bypass. Conceptually the finger printing simulations could be thought of as collecting buckets of water from various locations throughout the Delta. Each bucket examined would contain water from each source (Figure 1), however the relative contributions from each source would vary at each location for each time period that a bucket of water was analyzed.

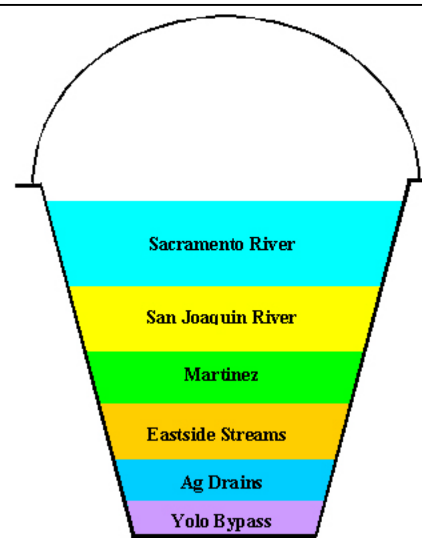

Figure 1: Conceptualization of Relative Source Contributions

The relative contributions of each flow source were simulated utilizing seven conservative tracer constituents denoted as CC1-CC7. Conservative tracer constituents 1 through 6 correspond to individual source locations (Figure 3). The constituent tracer concentrations were specified as a constant value at the source location (10,000 units in this case), and a value of zero is specified at all other locations. A seventh conservative tracer constituent is utilized to check mass conservation and is specified as the same constant value at each source (10,000 units in this case). Source concentrations are specified as 10,000 units to provide large concentrations that

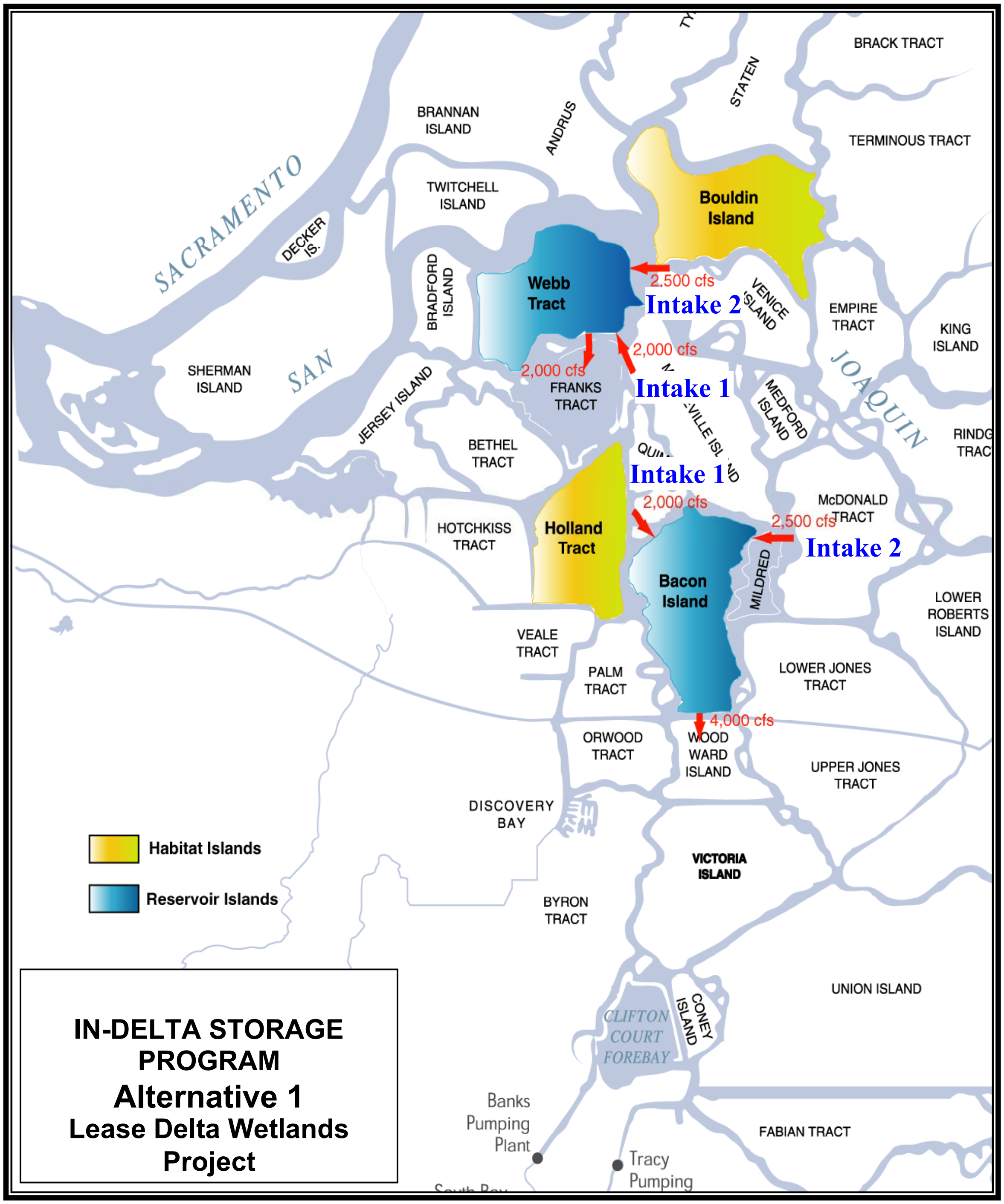

Figure 2: Proposed In-Delta Storage Alternative 1-Delta Wetlands Project with Original Intake and Release Locations

Figure adapted from draft document titled "In-Delta Storage Program: Description of Alternatives" dated 3/6/01

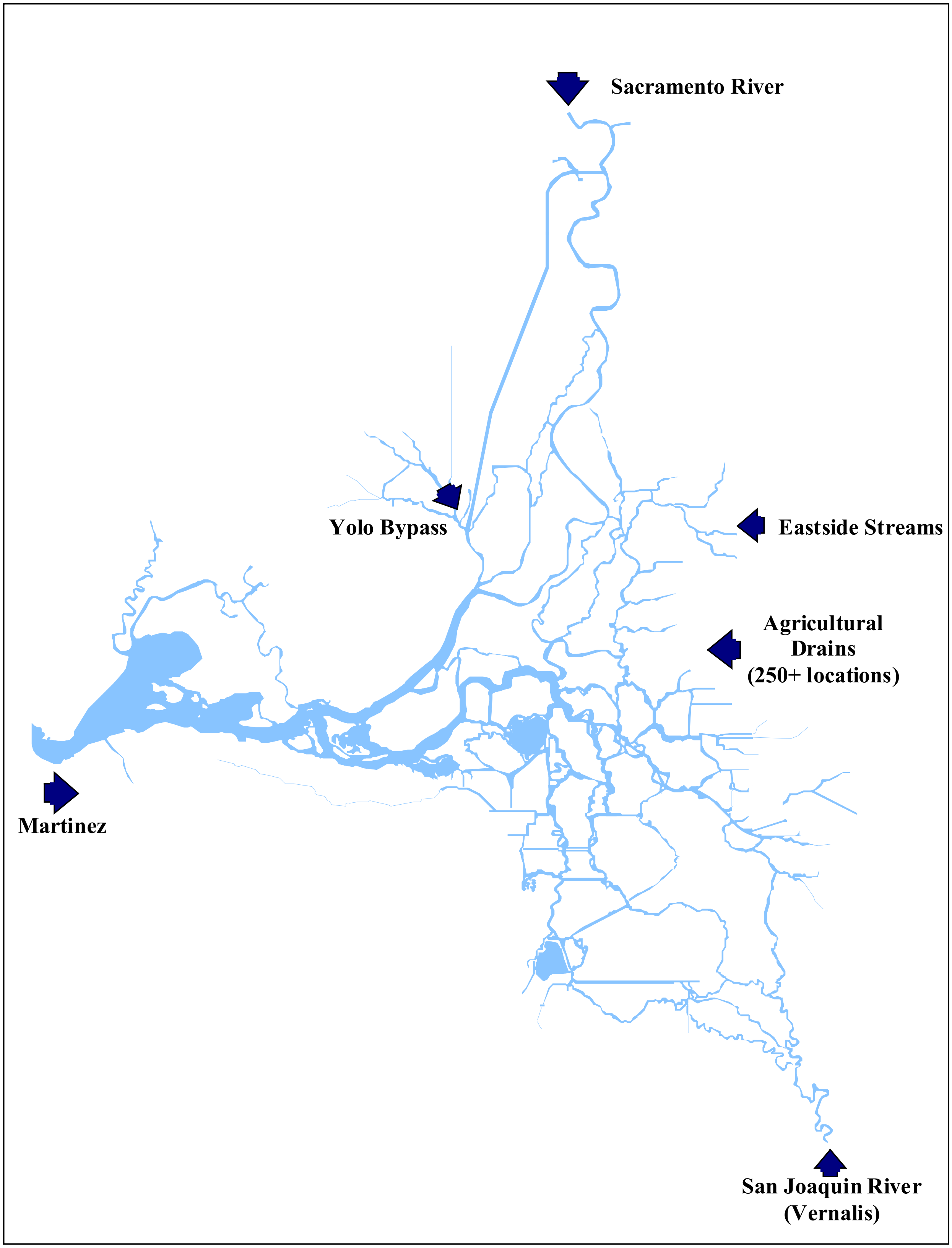

Figure 3: Source Locations for the Validation Fingerprinting Study

reduce round-off errors that occur at lower concentrations. Source locations corresponding to each conservative tracer constituent are indicated in Table 1. Specified concentrations of each conservative tracer constituent are given in Table 2.

Table 1: Conservative Tracer Constituents Simulated

Source Location	Conservative Constituent
Sacramento River	CC1
San Joaquin River	CC2
Martinez	CC3
Eastside Streams	CC4
Agricultural Drains	CC5
Yolo Bypass	CC6
All Sources	CC7

Table 2: Specified Source Tracer Concentations for In-Delta Storage Finger Printing

Location	CC1	CC2	CC3	CC4	CC5	CC6	CC7
Sac	10,000	0	0	0	0	0	10,000
SJR	0	10,000	0	0	0	0	10,000
Martinez	0	0	10,000	0	0	0	10,000
Eastside	0	0	0	10,000	0	0	10,000
Ag Drains	0	0	0	0	10,000	0	10,000
Yolo	0	0	0	0	0	10,000	10,000

If all of the initial conservative constituent tracer concentrations (CC1-CC6) are specified as the same constant value at the source location associated with each constituent and set equal to zero at all other source locations, when the system has reached dynamic steady state, the sum of the concentrations of conservative tracer constituents 1-6 at any location in the system should equal the specified concentration, 10,000 units in this case. Table 3 shows illustrative finger printing results for three hypothetical locations. At all three locations, the sum of the concentrations of conservative tracer constituents 1-6 equals the initial specified concentration of 10,000 units. For location A, the major source of water is the source associated with conservative tracer constituent 2 (the San Joaquin River-see Table 1) since 3500 units of the 10,000 units total concentration was contributed by that source. Similarly the source for conservative tracer constituent 3 (Martinez) is the major contributor at site B and the source associated with conservative tracer constituent 5 (agricultural drainage) is the main contributor at site C. For the example illustrated in Table 3, mass is conserved since the concentration of conservative tracer constituent 7 equals 10,000 units at all locations.

Table 3: Illustrative Examples of Finger Printing Conservative Tracer Constitutent Concentraitons at Three Locations

Location	CC1	CC2	CC3	CC4	CC5	CC6	CC7
A	1000	3500	500	3000	1250	750	10,000
B	2500	500	3000	2000	750	1250	10,000
C	1250	1750	1000	1500	3500	1000	10,000

For the In-Delta Storage finger printing study, the sum of the concentrations of the conservative tracer constituents 1-6 at any specified location equals the initial specified concentration of 10,000 units. (Equation 1). The value of conservative tracer constituent 7 at any location in the system should also equal the specified concentration as shown in Equation 2. Utilizing a tracer concentration of 10,000 units for each water source, the relative contribution of a specified source, n, at a given location is given by Equation 3, where CCn is the concentration of the conservative tracer constituent associated with the source n. Note that the relationships specified in Equations 1 - 3 are valid for conservative tracer concentrations of 10,000 units at each source location.

$$\sum_{n=1}^{6} CCn = 10,000\ units \quad \text{at any given location in the Delta} \qquad \text{Eqn. 1}$$

$$CC7 = 10,000\ units \quad \text{at any given location in the Delta} \qquad \text{Eqn. 2}$$

$$\mathrm{Re}\,lative\ contribution\ of\ source\, n\,(\%) = \frac{CCn}{10,000\ units} * 100\% \qquad \text{Eqn. 3}$$

For this study, twenty eight simulation output locations were chosen to provide a full coverage throughout the Delta including the intake and release locations for the Delta Wetlands project. The 28 output locations are shown in Figure 4.

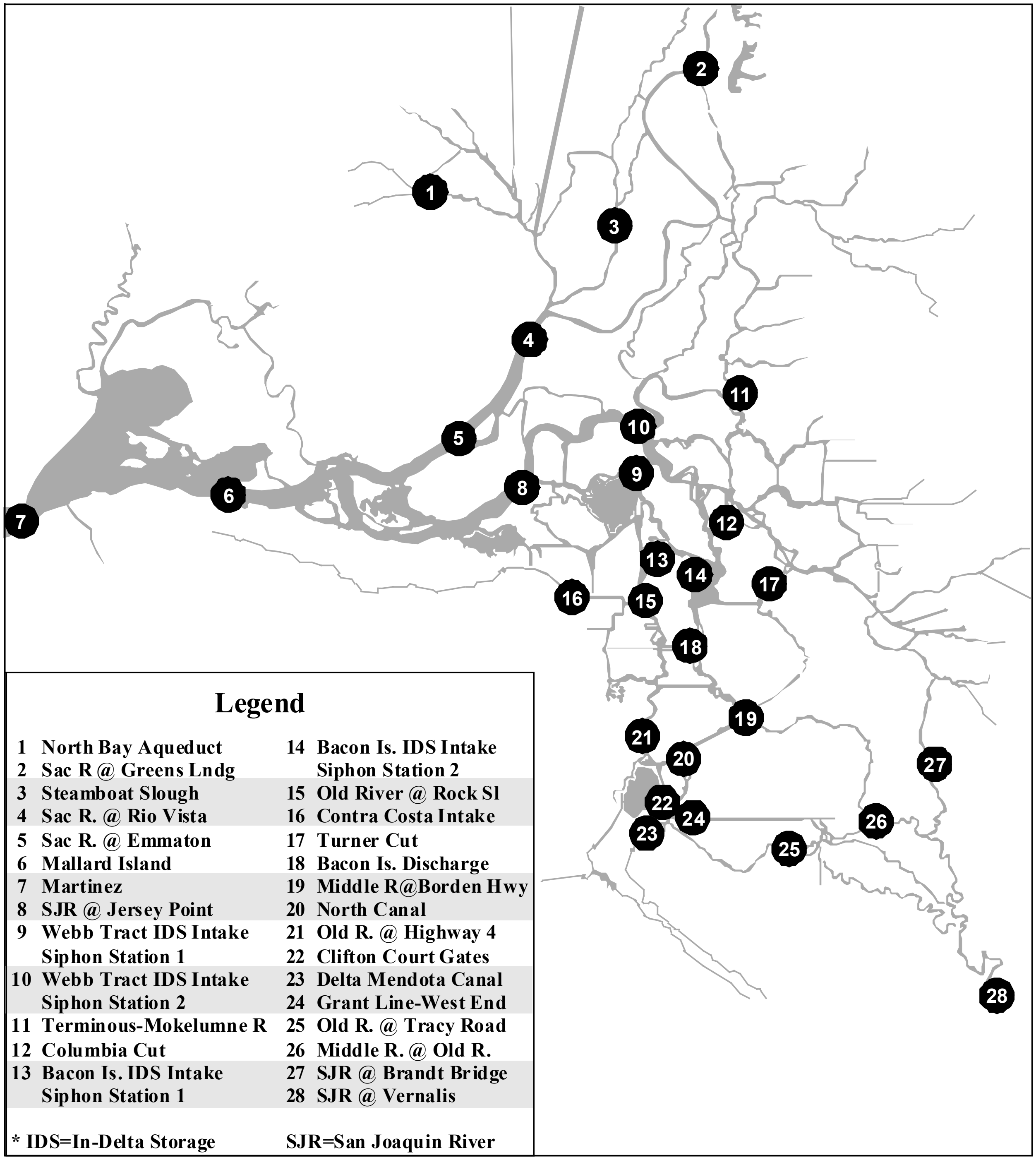

Figure 4: Validation Finger Printing Study Output Locations

Hydrology

The validation fingerprinting study simulates conditions for the time period March 1991 through September 1998. The distribution of water year types for this time period are presented in Figure 5 and Table 4.

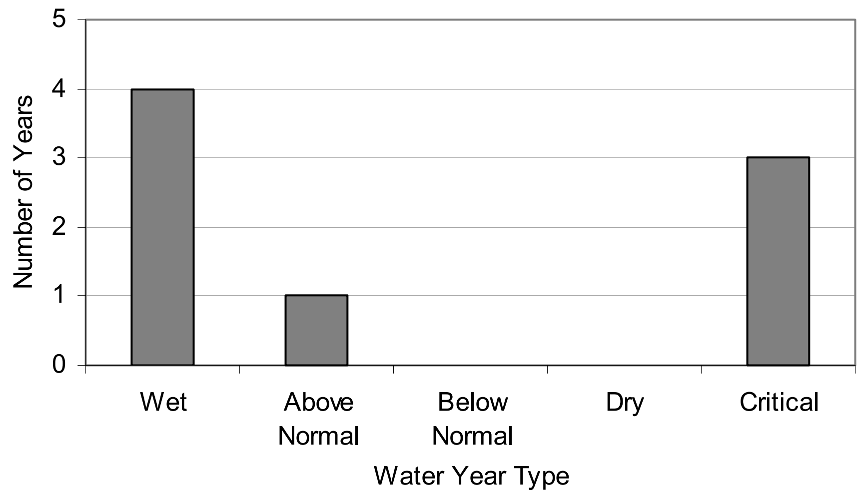

Figure 5: Distribution of Water Year Types for March 1991-September 1998

Table 4: Water Year Designations for 1991-1998

Water Year	SAC 40-30-30
1991	Critical
1992	Critical
1993	Above Normal
1994	Critical
1995	Wet
1996	Wet
1997	Wet
1998	Wet

Simulation Results

Time Series of Simulated Results

Simulation results were analyzed at several locations throughout the Delta (Figure 4). Four of the analysis locations correspond to export locations: Old River Rock Slough, Old River at Highway 4 (Los Vaqueros), Clifton Court Forebay, and the Delta Mendota Canal intake. Four additional analysis locations correspond to the original proposed intakes for the Delta Wetlands project: Webb Tract Intakes 1 and 2, and Bacon Island Intakes 1 and 2. Time series of relative flow contributions of the six water sources are shown for the export locations in Figure 9 and for the original Delta Wetlands intake locations in Figure 10. During dry hydrologic conditions of the first several years of the simulation, inflows from the Sacramento River provide the largest flow contribution at all eight locations. During the wetter hydrologic conditions in the last few years of the simulation, flow contributions from the San Joaquin River increase. Flow contributions from agricultural drainage rarely exceed 20% throughout the simulation period at all eight locations.

Comparison of monthly average flow contributions

Monthly distributions of relative flow contributions from six sources over the study period are shown in Figure 11 for the export locations and in Figure 12 for the original proposed Delta Wetlands intake locations. For Rock Slough, Clifton Court Forebay, and the Delta Mendota Canal intake, Sacramento River flows dominate during the summer, fall, and early winter months with flow contributions ranging from 40%-90%. However, during the winter and spring, flow contributions from the San Joaquin River approach and at times exceed those from the Sacramento River. At Clifton Court Forebay, flow contributions from the San Joaquin River exceed those from the Sacramento River in February through June. For the Old River at Highway 4 site, flow contributions from the San Joaquin River are greater throughout the year than for the other three export locations. Similar to the Clifton Court location, flow contributions from the San Joaquin River exceed those of the Sacramento River in February through June. For both the Clifton Court and Old River at Highway 4 locations, flow contributions from the San Joaquin River can exceed 60% during the winter and spring months. Flow contributions from agricultural drains were highest during the late winter and middle summer months. However, the flow contribution from the agricultural drains never exceeded 15%. All other sources contributed less than 10% of the flow in any given month.

For the Delta Wetlands sites, Sacramento River flows typically dominated. For both Webb Tract Intake locations, flow contributions from the Sacramento River ranged from 55% to 90% for all months. Flow contributions from the San Joaquin River were minor at the Webb Tract intake locations during the summer and fall months. During the winter and spring months, flow contributions from the San Joaquin River increased, but never exceeded 40%. Flow contributions at intake 2 at Bacon Island follow a similar pattern to the Webb Tract intakes. However, intake 1 at Bacon Island shows more influence from the San Joaquin River. Flow contributions from the San Joaquin are typically less than 20% during the summer and fall months, but increase to more than 60% during the winter and spring months. For all four intake locations, flow contributions from agricultural drains were highest during the late winter and middle summer months. However, the total flow contribution from the agricultural drains never exceeded 15%. All other sources contributed less than 10% of the flow in any given month.

Comparison of flow contributions during winter months for wet and dry years

Since high DOC concentrations are typically an issue of concern during wet months, the finger printing results were analyzed on a monthly basis. Since DOC concentrations tend to increase after major rainfall events, the monthly flow contributions for wet and critical years were analyzed separately. Relative flow contributions for the months of December and January in wet and dry years are shown for the eight analysis locations in Figure 13 through Figure 20. Relative flow contributions of the Sacramento River, San Joaquin River, and agricultural drainage during wet and dry years are summarized in Table 5 for the month of December and in Table 6 for the month of January.

At Old River at Rock Slough, the wintertime flow contributions of the San Joaquin River are much greater during the wet years (15% in December and 29% in January) compared to dry ones. For Old River at Rock Slough, San Joaquin River flow contributions are almost negligible during the critical years when the Sacramento River flow contributions were 90% or more during the winter months. Although wintertime flow contributions from agricultural drainage were less than 5% during dry years, these flow contributions exceeded the San Joaquin River's flow contributions of less than 2%. The largest flow contributions from agricultural drainage occurred during January of wet years, when 10% of the flow was provided by agricultural drainage.

A similar pattern of flow contributions results at Old River at Highway 4 (Los Vaqueros). Flow contributions of the San Joaquin River were much greater during wet years (27% in December and 36% in January) than in dry ones. During critical years, at Old River at Highway 4 the San Joaquin River contributed only 7% of the flow in December and only 2% of the flow in January. During the critical years, the Sacramento River flows dominated with contributions of 81% and 88% in December and January respectively. During wet years, the flow contributions from the Sacramento River dropped to 63% and 47% in December and January respectively. Agricultural drainage flow contributions during the winter months were typically around 6% except in January of wet years when the contribution increased to 12%.

At the two south Delta export locations, Clifton Court Forebay and the Delta Mendota Canal, the major flow contribution depended on the year type. During wet years the San Joaquin River provided the majority of the flow at the two export locations, and during dry years the Sacramento River contributed the majority of the flow. During wet years, the San Joaquin River contributed 52% and 57% of the flow at the Clifton Court Intake and 55% and 61% of the flow at the Delta Mendota Canal in December and January respectively. However during critical years, the Sacramento River provided the majority of the flow at Clifton Court Intake and the Delta Mendota Canal. During critical years Sacramento River flow contributions at Clifton Court Intake were 64% for both December and January, and flow contributions at Delta Mendota Canal were 56% for both December and January. Agricultural drainage flow contributions at both locations ranged from 4% to 7% for the winter months except in January of wet years when flow contributions increased to 10% at the Clifton Court Intake and 13% at the Delta Mendota Canal.

During winters of dry years all four original Delta Wetlands intake locations were dominated by Sacramento River flows. For the two Webb Tract intakes and Bacon Island Intake 1, Sacramento River flow contributions exceeded 90% in December and January of critical years. Flow contributions from the Sacramento River during critical years were slightly lower at Bacon Island Intake 2 (the southeastern most intake location) with values of 79% and 88% for December and January respectively. During wet years, the main source of flow at each intake location is the Sacramento River, but flow contributions are lower than in critical years. At the Webb Tract intakes, the Sacramento River contributes around 84% and 62% of the flow in

Table 5: Relative Flow Contributions of the Sacramento River, San Joaquin River and Agricultural Drains during December of Wet and Dry Years

Location	Sac Contribution Dec Wet Years	SJR Contribution Dec Wet Years	Ag Contributions Dec Wet Years	Sac Contribution Dec Critical Years	SJR Contribution Dec Critical Years	Ag Contributions Dec Critical Years
Old River at Rock Slough	76.2	15.0	5.3	89.8	1.6	3.7
Old River at Hwy 4	62.9	27.7	6.1	81.0	6.8	5.9
Clifton Court Intake	42.0	51.5	3.9	63.7	24.9	5.6
Delta Mendota Canal	38.2	55.2	4.2	55.8	33.7	5.3
Webb Tract Intake 1	83.0	8.1	3.5	92.9	0.4	2.7
Webb Tract Intake 2	84.2	6.6	2.9	94.4	0.3	2.3
Bacon Island Intake 1	78.0	13.3	4.9	90.6	1.2	3.4
Bacon Island Intake 2	63.0	25.0	6.1	78.8	8.1	5.5

Light gray shading indicates the major flow source at the specified location for the specified time period

Table 6: Relative Flow Contributions of the Sacramento River, San Joaquin River and Agricultural Drains during January of Wet and Dry Years

Location	Sac Contribution Jan Wet Years	SJR Contribution Jan Wet Years	Ag Contributions Jan Wet Years	Sac Contribution Jan Critical Years	SJR Contribution Jan Critical Years	Ag Contributions Jan Critical Years
Old River at Rock Slough	55.9	29.2	9.6	93.4	0.3	4.1
Old River at Hwy 4	47.1	36.4	11.8	87.9	2.3	6.7
Clifton Court Intake	29.9	56.8	10.1	64.2	26.3	6.8
Delta Mendota Canal	23.2	61.1	13.4	56.2	34.9	6.6
Webb Tract Intake 1	60.5	22.7	8.0	94.8	0.1	3.2
Webb Tract Intake 2	63.5	15.0	7.5	95.4	0.1	3.1
Bacon Island Intake 1	57.3	27.4	9.7	93.7	0.3	3.8
Bacon Island Intake 2	46.8	30.8	13.6	87.5	2.3	5.9

Light gray shading indicates the major flow source at the specified location for the specified time period

December and January. Sacramento River flows are also the major contribution at Bacon Island during wet winters, however contributions are greater for the western intake (Intake 1-flow contributions of 78% in December and 57% in January) than the eastern intake (Intake 2-flow contributions of 63% in December and 47% in January). At all four intake locations, San Joaquin River flow contributions are minor during critical years. However the San Joaquin River's flow contributions increased during wet winters. During wet winters at Webb Tract the San Joaquin River contributes 8% and 7% of the December flows at intakes 1 and 2 respectively. In January the San Joaquin River flow contributions increased to 23% and 15% at intakes 1 and 2 respectively. For Bacon Island during wet winters, San Joaquin flow contributions were higher than at Webb Tract with December flow contributions of 13% and 25% and January flow contributions of 27% and 31% at intakes 1 and 2 respectively. Wintertime agricultural drainage flow contributions were less than 6% at all intake locations except during January of wet years when agricultural drainage flow contributions increased to about 8% at the Webb Tract intakes and 10% at Bacon Island Intake 1 and 14% at Bacon Island Intake 2.

Use of Finger Printing to Estimate DOC Concentrations

DOC concentrations can be estimated utilizing the relative flow contributions determined by the DSM2 finger printing analysis. The DOC contribution at a given location from a specified source can be estimated by multiplying the DOC concentration of that source by the percent contribution of that source at that location. The total DOC concentration at the given location can be estimated by summing the estimated DOC contributions from each source (Eqn. 4).

$$DOC\ at\ a\ location = \sum_{Sources} DOC\ concentration\ source * \mathrm{Re}lative\ contribution\ of\ source \quad \text{Eqn. 4}$$

Note that using equation 4 and the relative flow contributions determined using the DSM2 fingerprinting analysis provides an estimate of DOC concentrations. This methodology does not account for field conditions other than flow rates and source concentrations. The type of finger printing used for this analysis indicates the relative contributions of each source to flow at a specified location, but there is no indication of the temporal distribution of the flow from each source. For example, the Sacramento River contribution at any given location may be composed of water that entered the Delta at different times and of different qualities. The analysis presented here considers all of the water contributed from a specified source to have a constant water quality. Thus affects of antecedent conditions and complex chemical interactions are not accounted for in this methodology.

To illustrate the use of finger printing results to estimate DOC concentrations, DOC concentrations were estimated at Old River at Highway 4 (Los Vaqueros) for wet and critical winters (Figure 6 and Figure 7 respectively). DOC source concentrations were assumed to be 0 mg/l at Martinez, 15 mg/l for the agricultural drainage, 5 mg/l for the San Joaquin River, and 3 mg/l for the eastside streams and Yolo Bypass. DOC source concentrations for the Sacramento River were varied from 3 mg/l to 6 mg/l to examine the sensitivity of the estimated DOC concentrations at Old River at Highway 4 to the range of DOC source concentrations typically observed in the Sacramento River. Relative flow contributions were determined from the DSM2 fingerprinting analysis. DOC concentrations at Old River at Highway 4 were estimated to range from 4.6 mg/l to 6.0 mg/l during wet years for Sacramento River DOC concentrations of 3 mg/l

Old River at Highway 4 (Los Vaqueros) for Wet Years
Sacramento River DOC = 3 mg/l

Source	Source DOC Concentration	Relative Flow Contribution	DOC Contribution
Sac	***3***	46.4	***1.4***
SJR	5	43.3	2.2
Martinez	0	0.2	0.0
Eastside	3	3.5	0.1
Ag Drains	15	6.3	0.9
Yolo	3	0.3	0.0
		TOTAL DOC	**4.6**

DOC Contribution = Source DOC concentration * Relative Flow Contribution(%)/100

Old River at Highway 4 (Los Vaqueros) for Wet Years
Sacramento River DOC = 6 mg/l

Source	Source DOC Concentration	Relative Flow Contribution	DOC Contribution
Sac	***6***	46.4	***2.8***
SJR	5	43.3	2.2
Martinez	0	0.2	0.0
Eastside	3	3.5	0.1
Ag Drains	15	6.3	0.9
Yolo	3	0.3	0.0
		TOTAL DOC	**6.0**

DOC Contribution = Source DOC concentration * Relative Flow Contribution(%)/100

Figure 6: Sample Computations of Estimated DOC Concentrations at Old River at Highway 4 for Wet Years

Old River at Highway 4 (Los Vaqueros) for Critical Years
Sacramento River DOC = 3 mg/l

Source	**Source DOC Concentration**	**Relative Flow Contribution**	**DOC Contribution**
Sac	***3***	77.2	***2.3***
SJR	5	5.2	0.3
Martinez	0	1.0	0.0
Eastside	3	2.4	0.1
Ag Drains	15	10.2	1.5
Yolo	3	0.2	0.0
		TOTAL DOC	**4.2**

DOC Contribution = Source DOC concentration * Relative Flow Contribution(%)/100

Old River at Highway 4 (Los Vaqueros) for Critical Years
Sacramento River DOC = 6 mg/l

Source	**Source DOC Concentration**	**Relative Flow Contribution**	**DOC Contribution**
Sac	***6***	77.2	**4.6**
SJR	5	5.2	0.3
Martinez	0	1.0	0.0
Eastside	3	2.4	0.1
Ag Drains	15	10.2	1.5
Yolo	3	0.2	0.0
		TOTAL DOC	**6.5**

DOC Contribution = Source DOC concentration * Relative Flow Contribution(%)/100

Figure 7: Sample Computations of Estimated DOC Concentrations at Old River at Highway 4 for Critical Years

and 6 mg/l respectively. Similarly for critical years, DOC concentrations were estimated to range from 4.2 mg/l to 6.5 mg/l for Sacramento River DOC concentrations of 3 mg/l and 6 mg/l respectively.

Sensitivity of estimated wintertime Delta DOC concentrations to DOC source concentrations from agricultural drainage and the Sacramento and San Joaquin Rivers were examined for each of the eight output locations. At each location, source DOC concentrations were varied over the range of values observed in the field. Sacramento River DOC concentrations were varied from 3 to 6 mg/l, San Joaquin River DOC concentrations were varied from 3 to 9 mg/l, and agricultural drainage DOC values were varied from 5 to 35 mg/l. Monthly average DOC concentrations for December and January were estimated at each location for each combination of source DOC concentrations for both wet and critical years.

Figure 8 illustrates ranges of DOC concentrations estimated by varying DOC concentrations at one source (either the Sacramento River, San Joaquin River or agricultural drainage) and holding all other source DOC concentrations constant at values typically observed in the field. To synthesize the analysis results, the eight locations were divided into three groups. Webb Tract intakes 1 and 2 and Bacon Island intakes 1 and 2 were grouped as In-Delta Storage intakes. Old River at Rock Slough and Old River at Highway 4 were grouped as Old River intakes. Finally, Clifton Court and Delta Mendota Canal were grouped together. Average minimum and maximum estimated DOC concentrations for each group were computed for the scenarios varying the DOC source concentrations (Table 7).

Typically maximum estimated DOC concentrations in December and January were higher during wet years than during critical years at all locations for the scenarios varying source DOC concentrations from the Sacramento River, San Joaquin River, and agricultural drainage (Figure 8 and Table 7). Minimum estimated DOC concentrations for December and January were similar for both wet and critical years.

For December and January of critical years, highest average maximum DOC concentrations throughout the system were estimated when DOC concentrations in the Sacramento River were high (Figure 8 and Table 7). This is due to the large flow contributions from the Sacramento River during critical years at all of the sites examined (Table 5 and Table 6). During December and January of critical years, varying the DOC concentrations in the San Joaquin River and in agricultural drainage produced minor changes in estimated DOC concentrations except at Clifton Court and the Delta Mendota Canal. This is due to the fact that the Clifton Court and Delta Mendota Canal sites were the only sites examined where the San Joaquin River made significant flow contributions during critical years (Table 5 and Table 6). Flow contributions from agricultural drainage were less than 7% at all locations during critical years. Thus, for the In-Delta Storage and Old River intakes the DOC of the Sacramento River inflows had the largest effect on estimated DOC concentrations for December and January of critical years. However, at Clifton Court and at the Delta Mendota Canal the ranges of influence on estimated DOC in December of critical years were similar for all three inflows examined (Sacramento River, San Joaquin River, and agricultural drainage). In January of critical years, the inflows from the San Joaquin River and

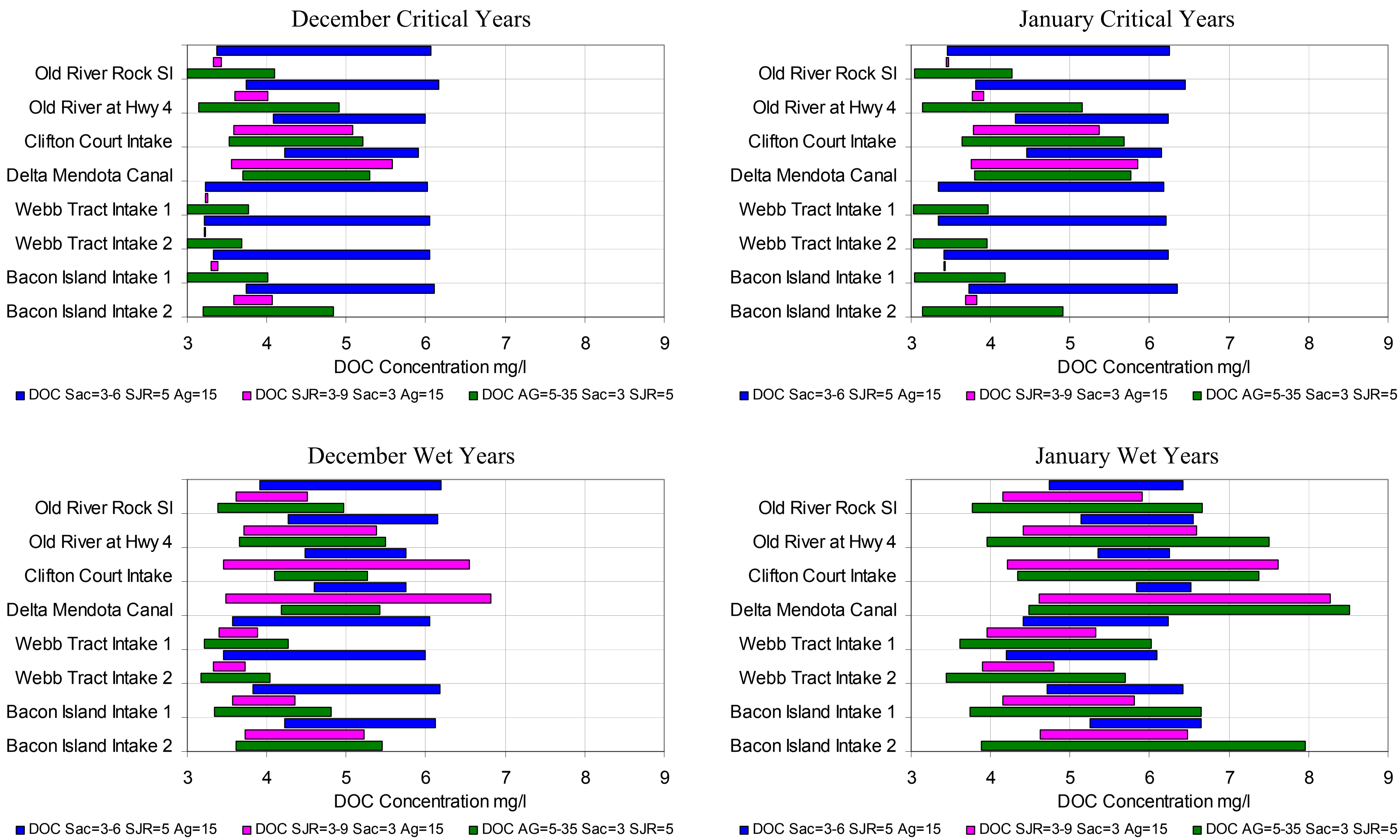

Figure 8: Range of Estimated DOC Concentrations for December and January of Wet and Critical Years

Table 7: Summary of Average Minimum and Maximum Estimated DOC Concentrations

Location	In-Delta Storage Intakes*			Old River Intakes**			Clifton Court and Delta Mendota Canal		
Varied DOC Source	**Sac**	**SJR**	**Ag**	**Sac**	**SJR**	**Ag**	**Sac**	**SJR**	**Ag**
Average Minimum DOC Dec Critical Yrs	3.4	3.3	3.0	3.5	3.5	3.1	4.2	3.6	3.6
Average Maximum DOC Dec Critical Yrs	6.1	3.5	4.0	6.1	3.7	4.1	5.9	5.3	5.2
Average Minimum DOC Dec Wet Yrs	3.8	3.5	3.3	4.1	3.7	3.5	4.5	3.5	4.1
Average Maximum DOC Dec Wet Yrs	6.1	4.3	4.6	6.2	4.9	5.2	5.7	6.7	5.3
Average Minimum DOC Jan Critical Yrs	3.5	3.4	3.1	3.6	3.6	3.1	4.4	3.8	3.7
Average Maximum DOC Jan Critical Yrs	6.2	3.5	4.3	6.4	3.7	4.7	6.2	5.6	5.7
Average Minimum DOC Jan Wet Yrs	4.6	4.2	3.7	4.9	4.3	3.9	5.6	4.4	4.4
Average Maximum DOC Jan Wet Yrs	6.4	5.6	6.6	6.5	6.3	7.1	6.4	7.9	7.9

* In-Delta Storage intakes are Webb Tract intakes 1 and 2 and Bacon Island intakes 1 and 2
**Old River intakes are Old River at Rock Slough and Old River at Highway 4

agricultural drainage had the greatest impact on estimated DOC concentrations at Clifton Court and at the Delta Mendota Canal.

During December and January of wet years, the influence of flow contributions from the San Joaquin River and agricultural drainage becomes more significant in DOC estimations (Figure 8 and Table 7). Similar to the results for critical years, for December of wet years the highest estimated DOC concentrations at the In-Delta Storage and Old River intakes were associated with the high DOC concentrations in the Sacramento River since the Sacramento River was the major flow contributor at those locations during that time period (Table 5). However at Clifton Court and at the Delta Mendota Canal, the San Joaquin River provided the majority of the flow in December and January of wet years (Table 5), and thus the highest estimated DOC concentrations at those locations in those months were associated with high DOC levels in the San Joaquin River. In January of wet years, flow contributions from agricultural drainage increased at all locations (Table 6) and ranged from 7.5% to 13.6%. Although agricultural drainage did not provide the largest flow contribution in January of wet years, the flow contributions became large enough that the largest estimated DOC values throughout the system occurred at the highest agricultural drainage DOC concentrations of 35 mg/l. Thus, a very high source DOC concentration can have a large impact on the total estimated DOC at a given location even if the flow contribution from that source is relatively minor.

Summary-Conclusions

Relative flow contributions from six sources were examined for the time period March 1991 through September 1998. The six sources examined were the Sacramento River, San Joaquin River, Martinez, eastside streams, agricultural drains, and the Yolo Bypass. Simulation results are detailed in this memo for eight selected locations. Four of the analysis locations correspond to export locations: Old River Rock Slough, Old River at Highway 4 (Los Vaqueros), Clifton Court Forebay, and the Delta Mendota Canal intake. Four additional analysis locations correspond to the original intakes for the Delta Wetlands project: Webb Tract Intakes 1 and 2, and Bacon Island Intakes 1 and 2.

Since high DOC concentrations are typically an issue of concern during wet months, the finger printing results were analyzed on a monthly basis. Since DOC concentrations tend to increase after major rainfall events, monthly flow contributions for wet and critical years were analyzed separately. For all eight locations, the Sacramento River provided the major flow contribution during winters of critical years (56%-95%), and San Joaquin River flow contributions were highest during January of wet years (15%-62%). During winters of wet years San Joaquin River flow contributions increased at all locations, and in fact provided the majority of the flow at both the Clifton Court Intake and the Delta Mendota Canal. As might be expected based on their relative locations, San Joaquin River flow contributions were higher for the Bacon Island intake locations than for the Webb Tract locations in both wet and critical years. Agricultural drainage flow contributions were less than 6% at all locations except during January of wet years when the flow contribution increased up to 14%. Agricultural drainage flow concentrations were typically higher at the southern locations (the four export locations and at Bacon Island Intake 2) than at the more northern locations (the Webb Tract intakes and Bacon Island Intake 1).

Finger printing results for flow contributions for the winter months during wet and critical years were utilized to estimate ranges of DOC concentrations at the four export locations and at the four original Delta Wetlands intake locations. During December and January of critical years the highest average maximum DOC concentrations throughout the system were estimated when DOC concentrations in the Sacramento River were high since the Sacramento River provided the major flow contribution during those time periods. During December and January of critical years, varying the DOC concentrations in the San Joaquin River and in agricultural drainage produced minor changes in estimated DOC concentrations except at Clifton Court and the Delta Mendota Canal. This is due to the fact that the Clifton Court and Delta Mendota Canal sites were the only sites examined where the San Joaquin River made significant flow contributions during critical years. Additionally, flow contributions from agricultural drainage were less than 7% at all sites during critical years. In winters of wet years, the highest estimated DOC concentrations were associated with high DOC concentrations for the major flow contributor at each location (the Sacramento River for the In-Delta Storage and Old River intakes and the San Joaquin River for Clifton Court and the Delta Mendota Canal). In January of wet years, flow contributions from agricultural drainage increased to levels that produced the highest estimated DOC concentrations at all locations when the DOC concentrations of the agricultural drainage were high. Thus, a very high source DOC concentration can have a large impact on the total estimated DOC at a given location even if the flow contribution from that source is relatively minor.

In summary, DSM2 finger printing simulations were conducted to analyze the relative flow contributions of six sources throughout the Delta. Simulation results were examined at four export and the four original Delta Wetlands intake locations. Relative flow contributions from the six sources were analyzed as time series over the entire simulation period and on a monthly basis for both wet and critical years. The simulated relative flow contributions were then utilized to conduct a sensitivity analysis of estimated DOC concentrations at the eight study sites. Typically estimated DOC concentrations were highest when there were high DOC levels in the flow source that provided the major flow contribution for winters of both critical and wet years. However, during January of wet years, flow contributions from agricultural drainage increased to levels high enough that the highest estimated DOC concentrations were produced when the DOC concentrations of the agricultural drainage were high. The DSM2 finger printing technique provides a useful tool for sensitivity analysis of boundary condition effects on water quality at selected Delta locations.

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Pandey, Ganesh (2001). "Chapter 3: Simulation of Historical DOC and UVA Conditions in the Delta." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 22nd Annual Progress Report to the State Water Resources Control Board*. California Department of Water Resources. Sacramento, CA.

Time Series of Simulation Results

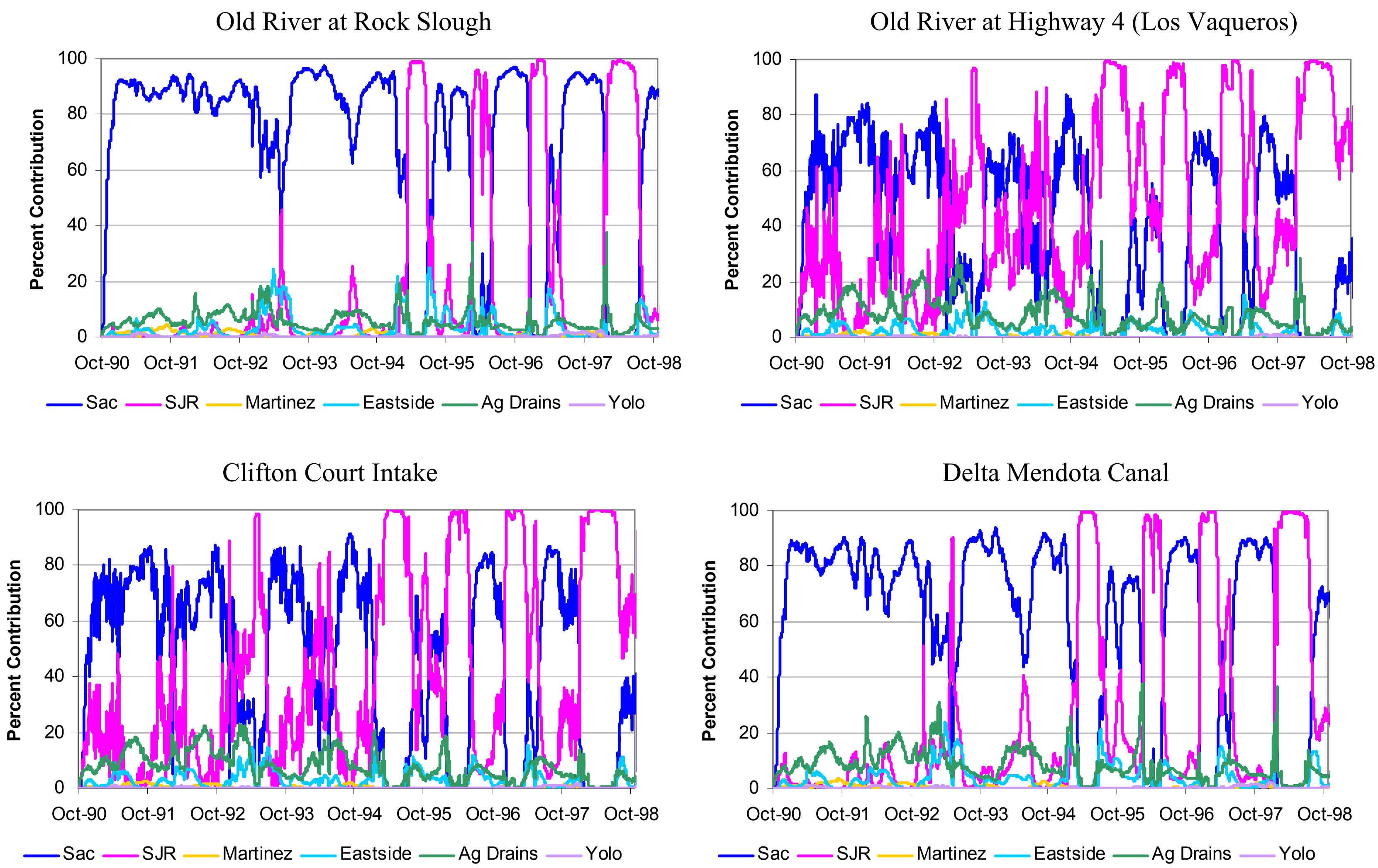


Figure 9: Time Series of Simulated Relative Contributions of Flow Sources at Delta Export Locations

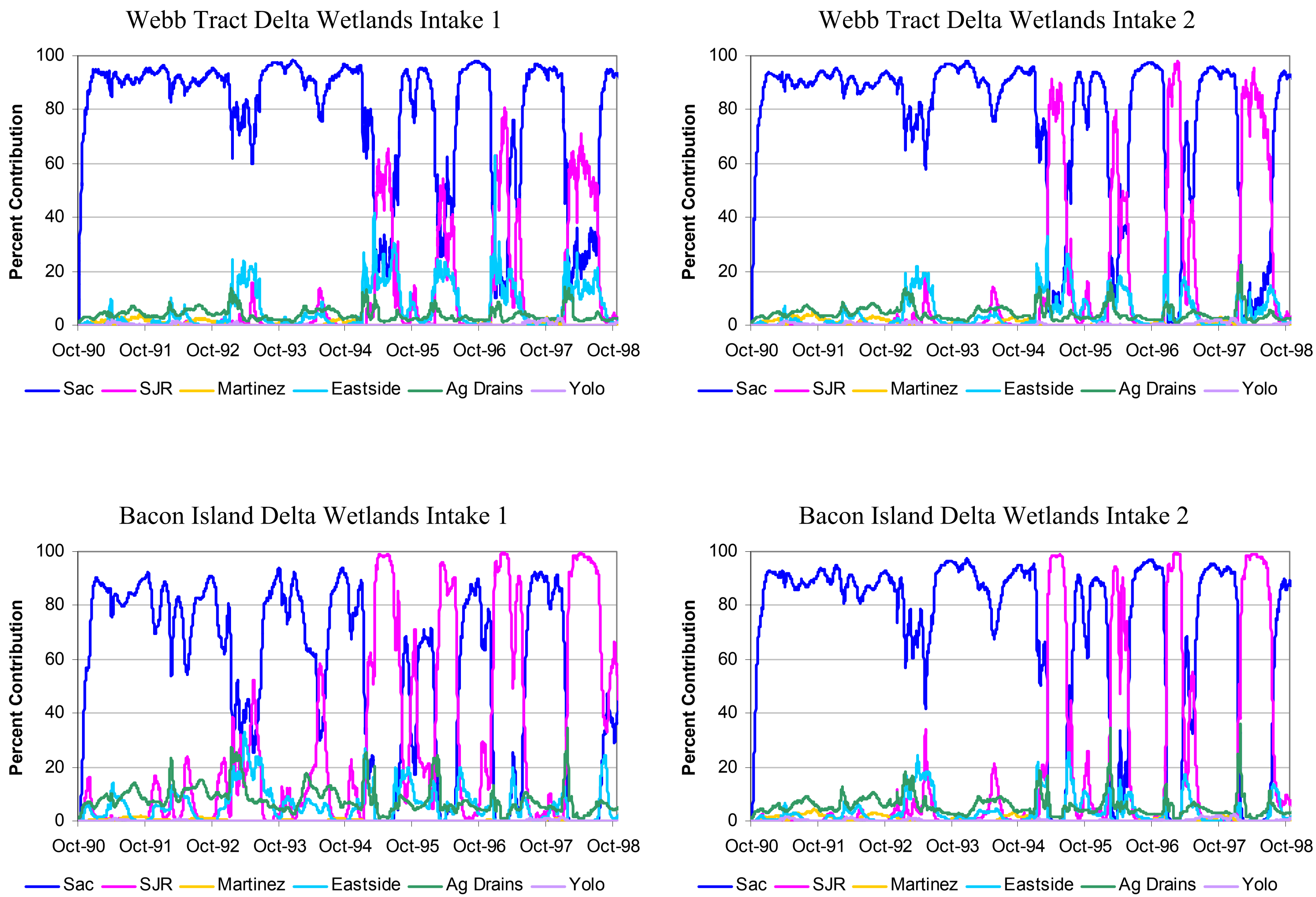
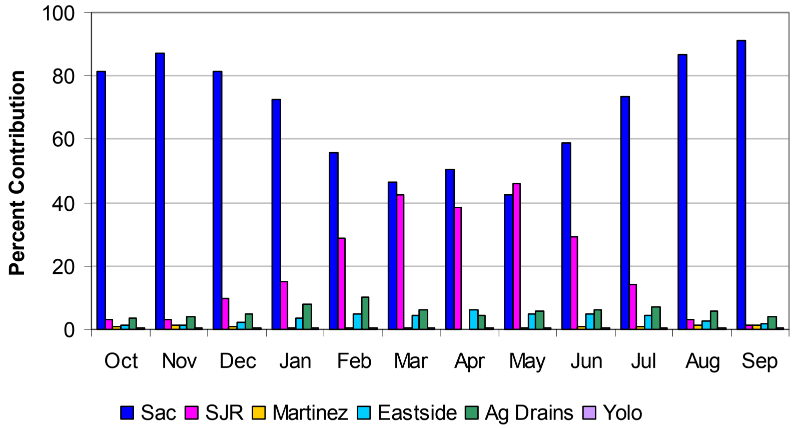


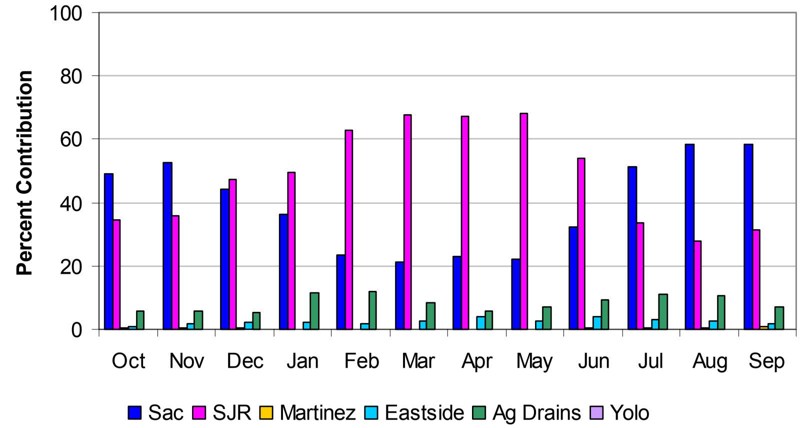
Figure 10: Time Series of Simulated Relative Contributions of Flow Sources at the Original Delta Wetlands Intake Locations

Monthly Average Simulation Results

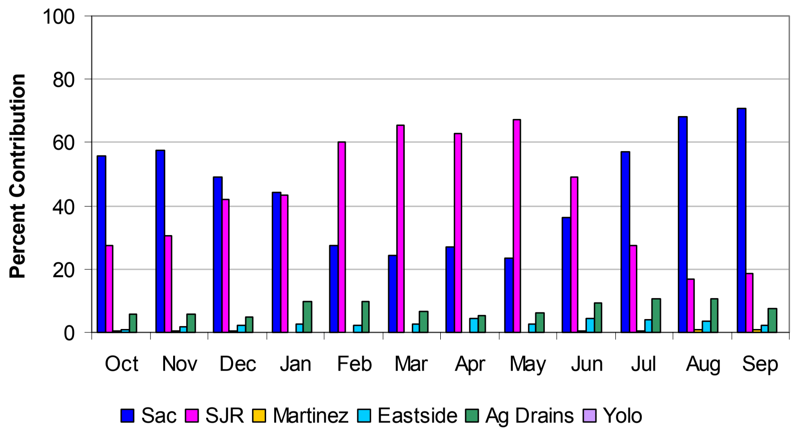
Old River at Rock Slough



Old River at Highway 4 (Los Vaqueros)



Clifton Court Intake



Delta Mendota Canal

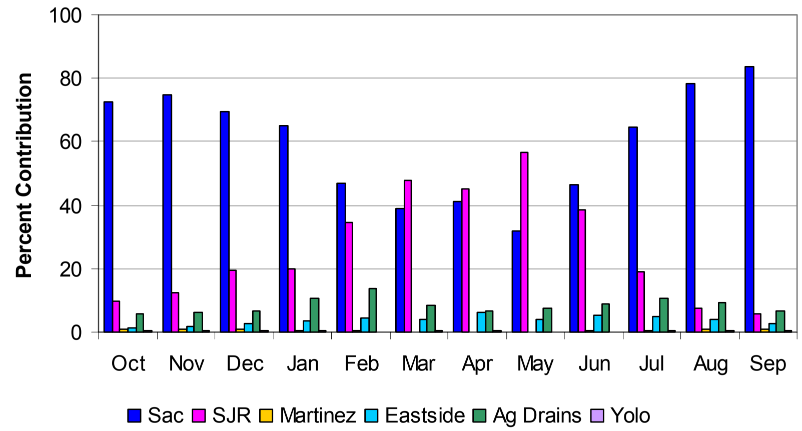
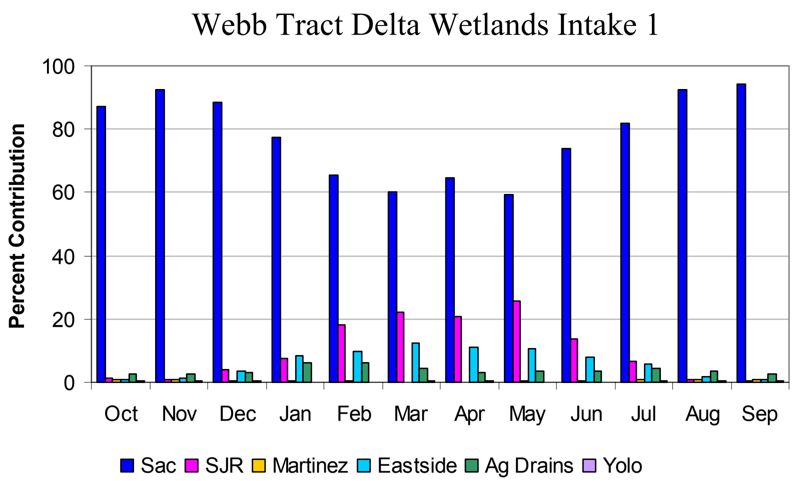
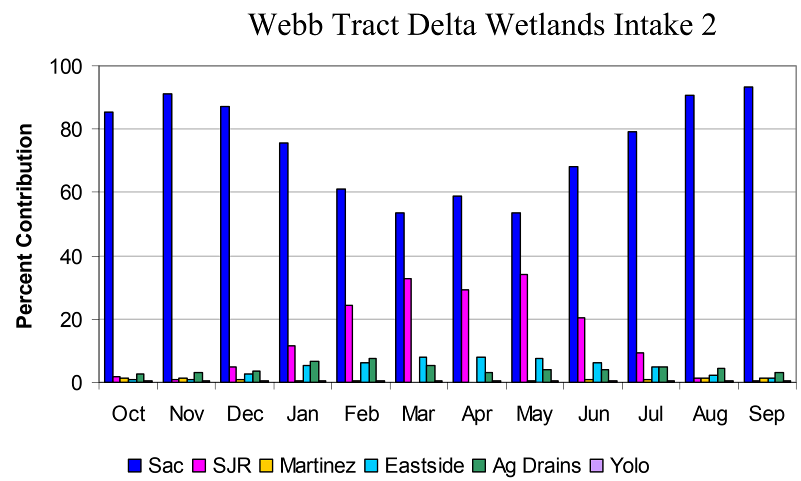
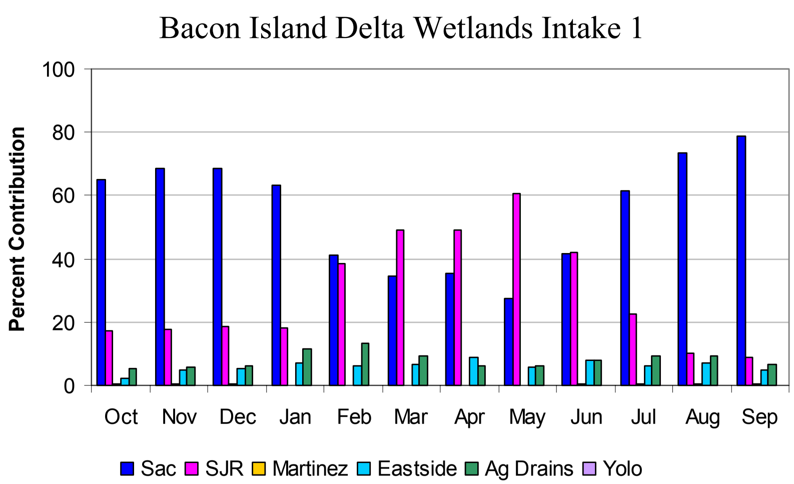


Figure 11: Monthly Average Simulated Relative Contributions of Flow Sources at Delta Export Locations for March 1991-September 1998







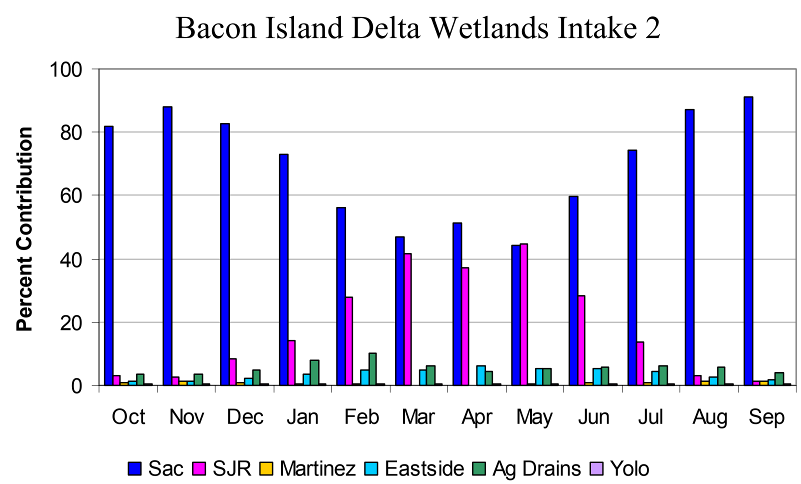


Figure 12: Monthly Average Simulated Relative Contributions of Flow Sources at the Original Proposed Delta Wetlands Intake Locations for March 1991-September 1998

Simulation Results for Winters of Wet and Critical Years

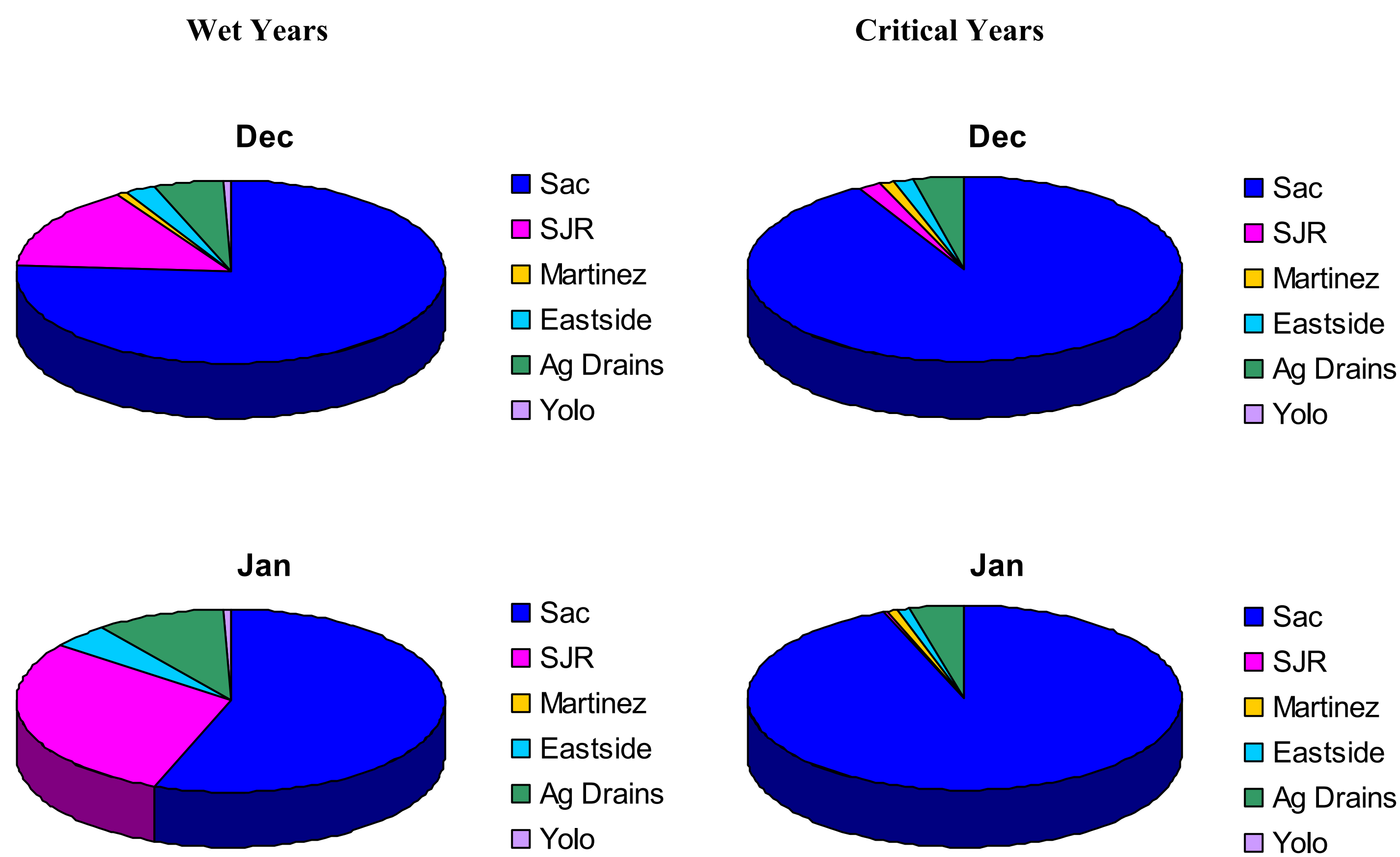


Figure 13: Simulated Relative Contributions of Flow Sources for Old River at Rock Slough for March 1991-September 1998

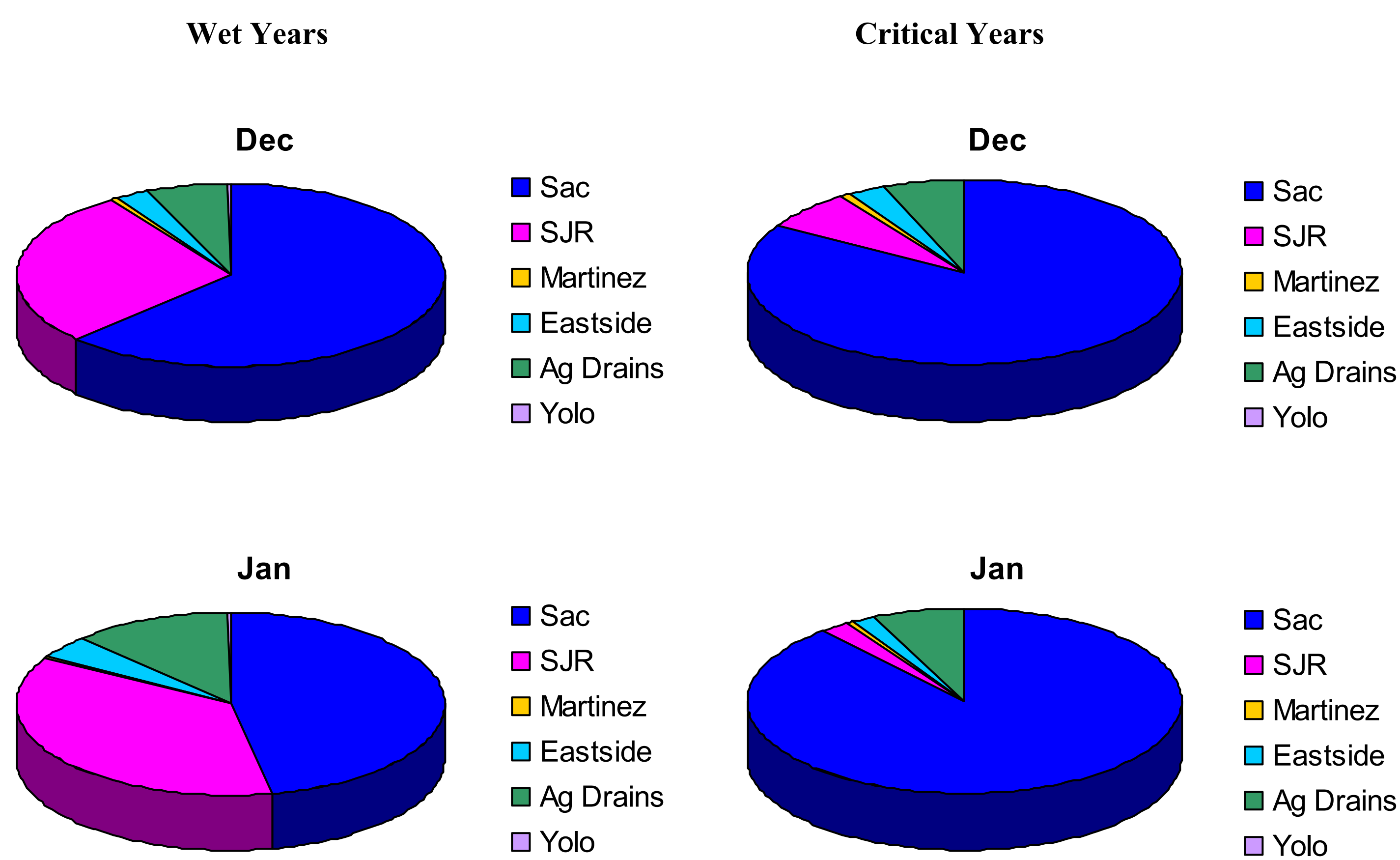


Figure 14: Simulated Relative Contributions of Flow Sources for Old River at Highway 4 (Los Vaqueros) for March 1991-September 1998

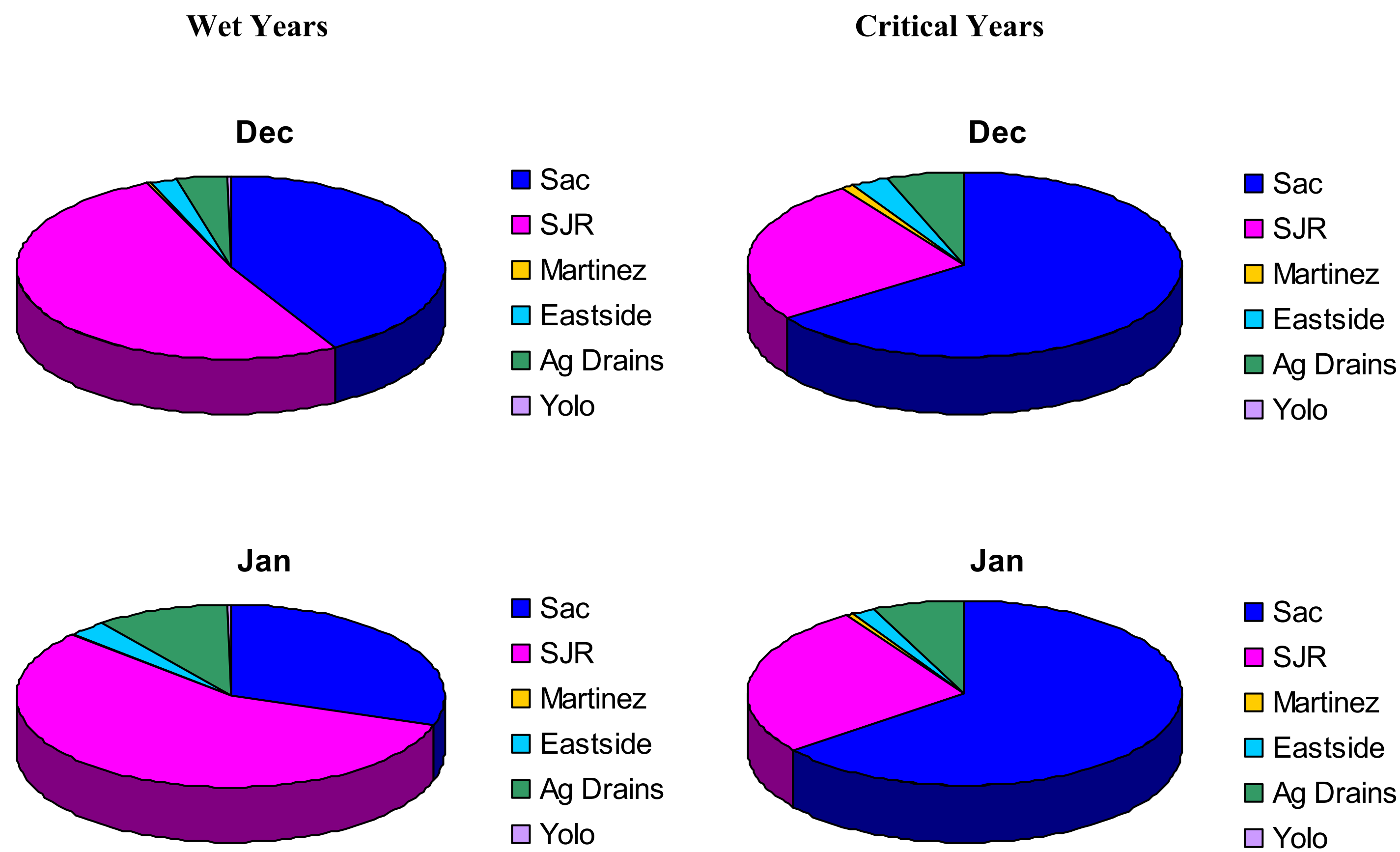


Figure 15: Simulated Relative Contributions of Flow Sources for Clifton Court Intake for March 1991-September 1998

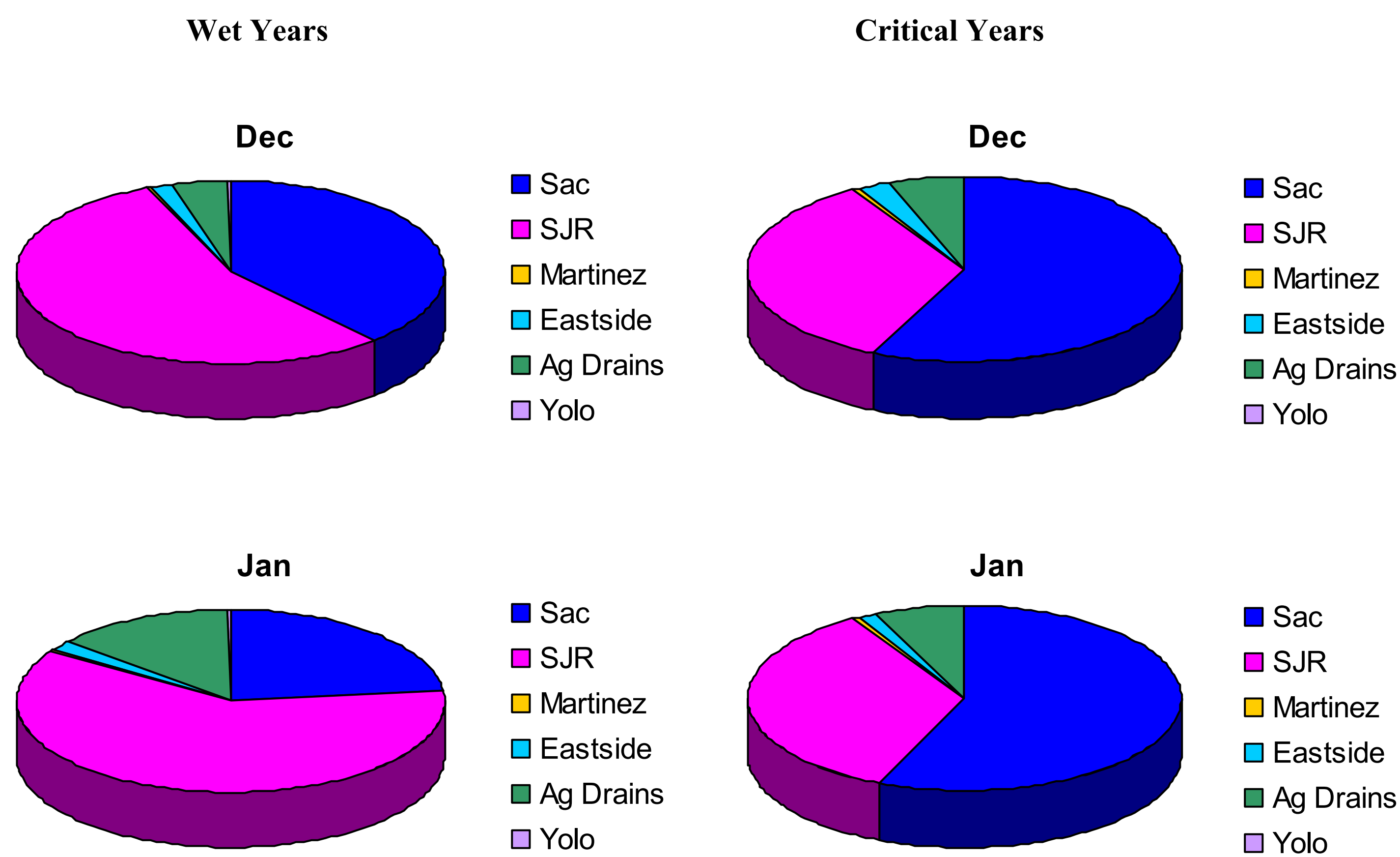


Figure 16: Simulated Relative Contributions of Flow Sources for Delta Mendota Canal for March 1991-September 1998

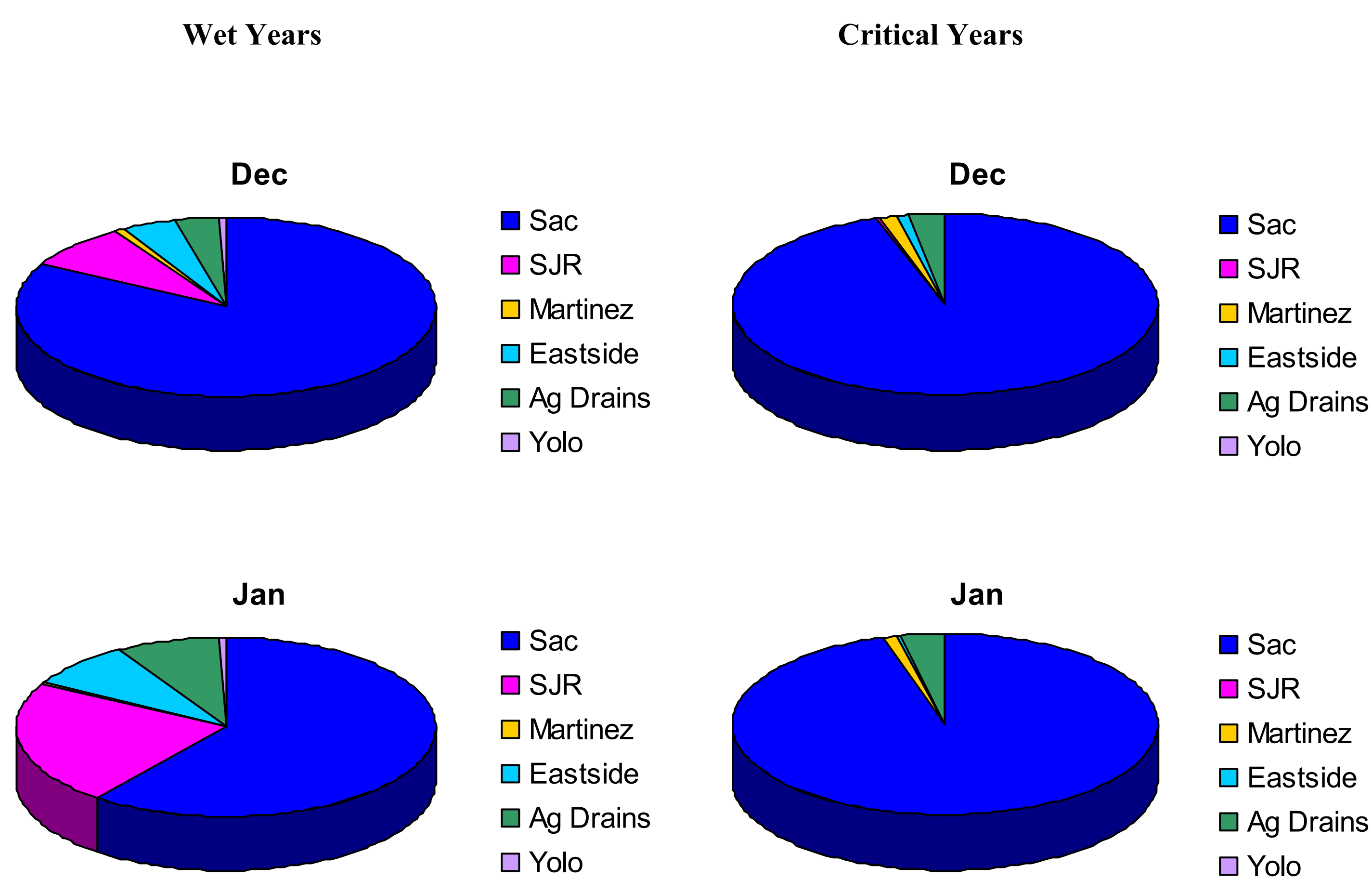


Figure 17: Simulated Relative Contributions of Flow Sources for Webb Tract Intake 1 for March 1991-September 1998

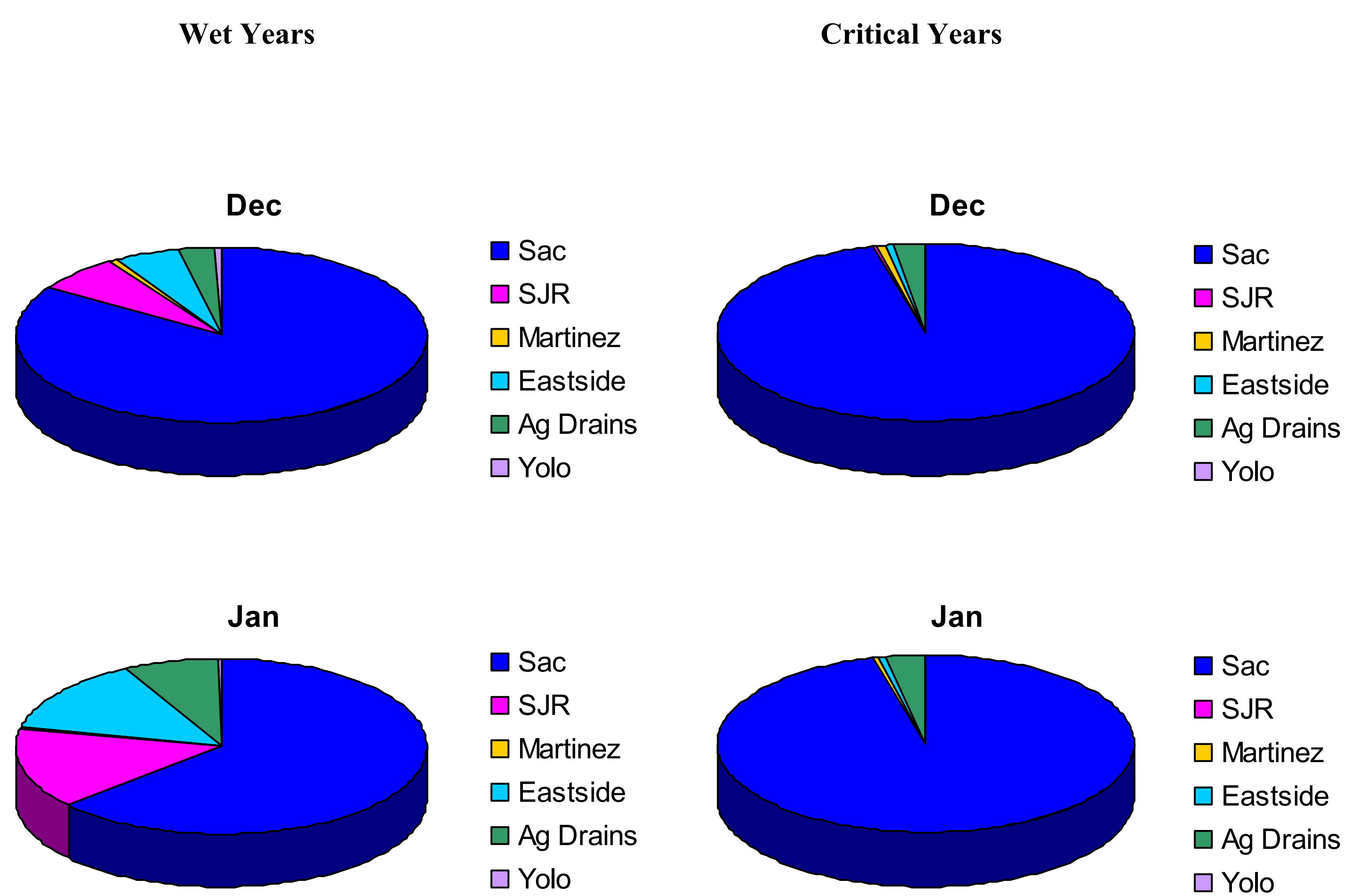


Figure 18: Simulated Relative Contributions of Flow Sources for Webb Tract Intake 2 for March 1991-September 1998

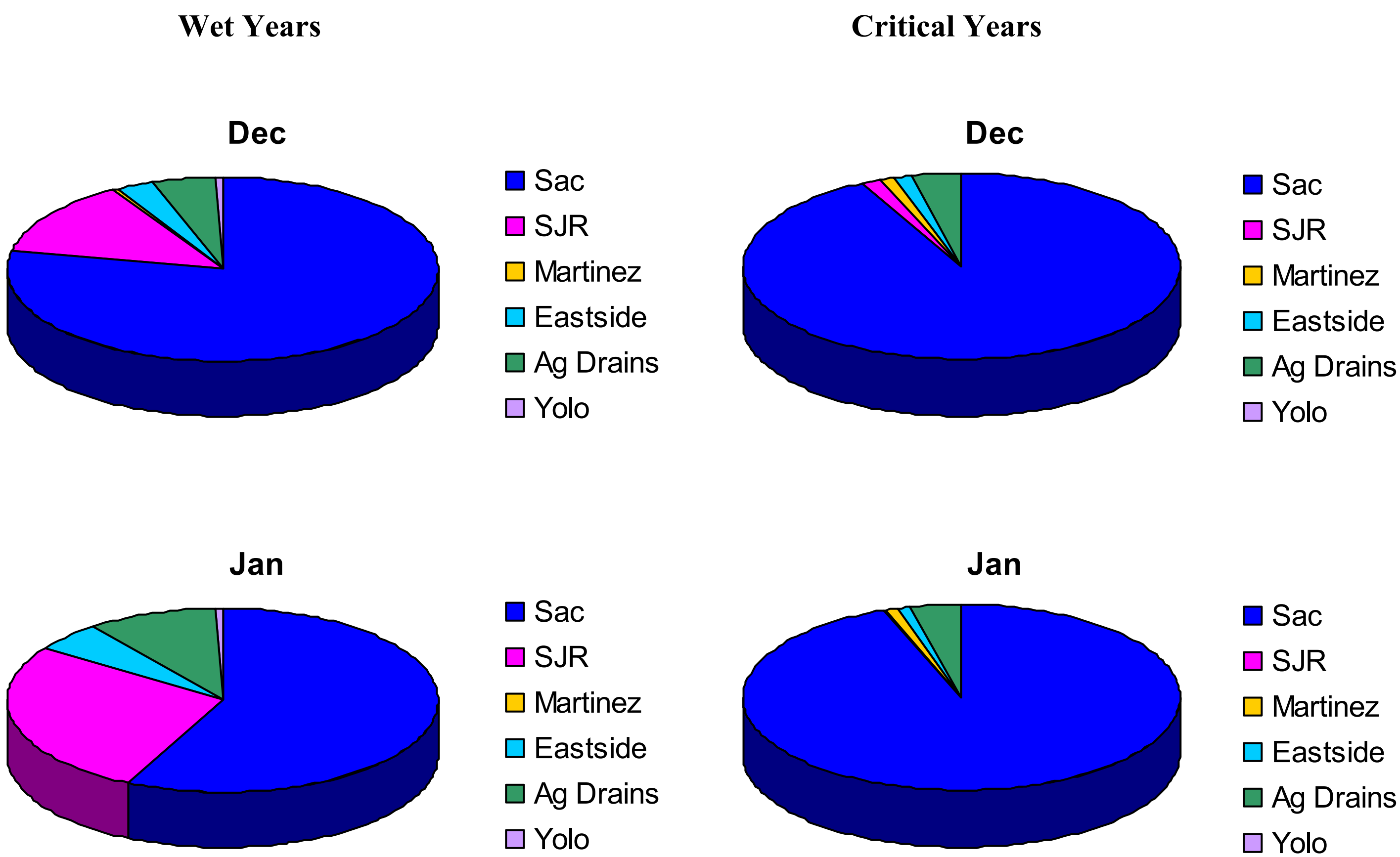


Figure 19: Simulated Relative Contributions of Flow Sources for Bacon Island Intake 1 for March 1991-September 1998

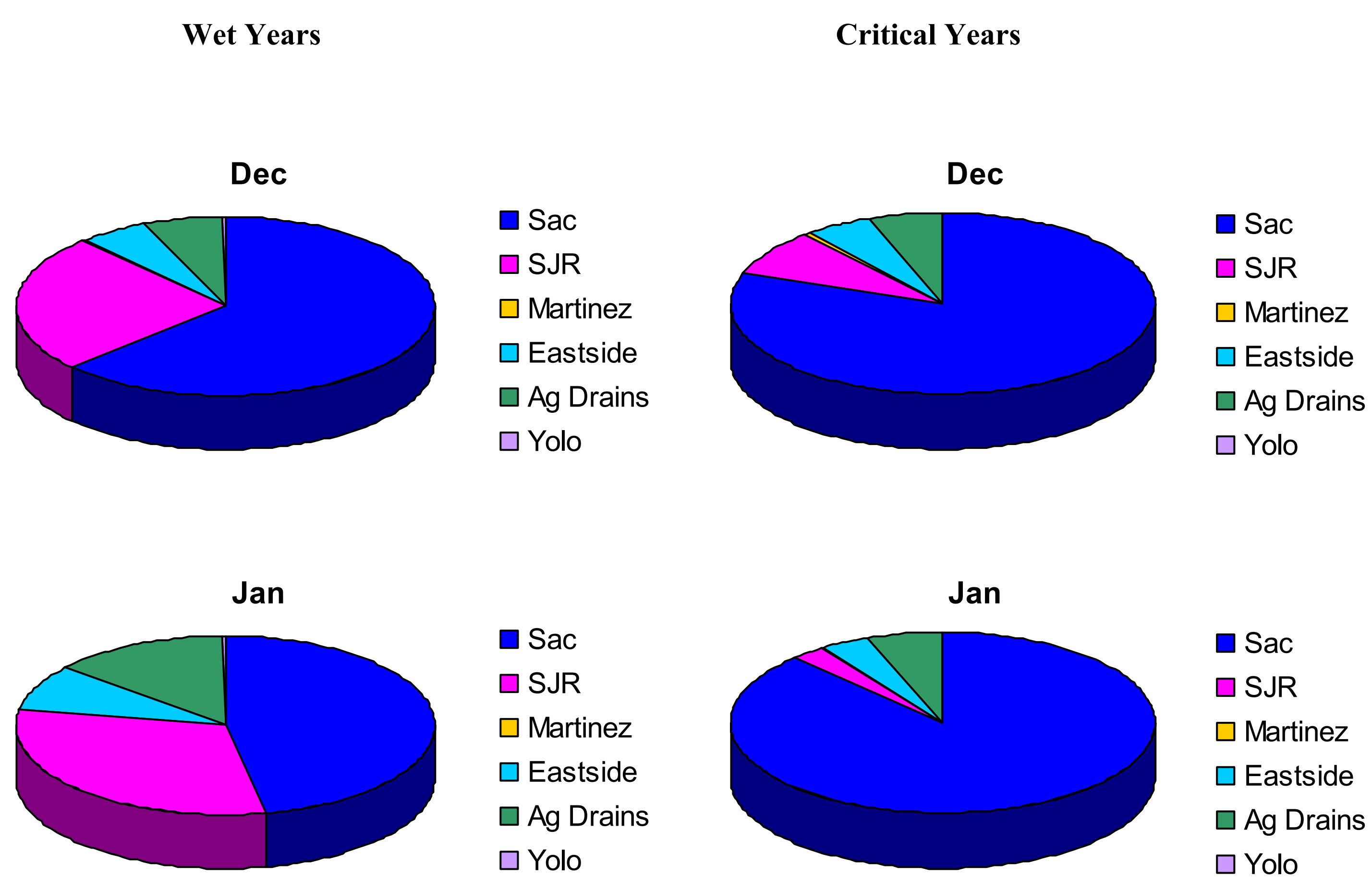


Figure 20: Simulated Relative Contributions of Flow Sources for Bacon Island Intake 2 for March 1991-September 1998

OFFICE MEMO

TO: Paul Hutton	**DATE:** September 17, 2001
FROM: Tara Smith	**SUBJECT:** Delta Wetlands Preliminary Delta Simulation Model 2 (DSM2) Studies

Introduction

Several 16-year DSM2 planning studies were simulated using the same hydrology and project island operations used for the Delta Wetlands EIR. These simulations provided output that showed the effects of the Delta Wetlands operations on Electrical Conductivity (EC), ultraviolet absorbance at 254 nm (UVA), dissolved organic carbon (DOC), Total Trihalomethane (TTHM), and Bromate (BRM). The purpose of doing these studies was: to evaluate the Delta Wetlands proposed operation, to establish a way to evaluate transport and fate of constituents not normally modeled in a planning study, and to set up studies so that the template would be ready for the more refined in Delta storage simulations.

These studies include an existing Delta condition with no Delta Wetland project islands in operation and a plan condition with the project islands in operation. Results and analyses for both conditions are shown in the attached report, and a brief summary of major findings is listed below.

Description of Simulations

Both the base and plan condition used a DWRSIM 771 hydrology for the boundary inflows and exports. In the plan hydrology, water was diverted onto the project islands when the Delta was in excess flow conditions. Water was pumped into the channels from the islands when the Delta was in balance and when there was pumping capacity available. For both the base and the plan conditions, simulations were run using three different constituents, EC, UVA and DOC. TTHM and BRM values were calculated from relationships between DOC, UVA, EC, and temperature. (Average monthly temperatures were obtained from the Contra Costa water treatment plant and used in the relationship).

The EC quality of water returned to the channels from the project island reservoirs was a mixture of the various diversion qualities found in the project islands. Since there is uncertainty concerning the DOC and UVA water quality leaving the islands due to the interaction of the water with the island, the return quality for DOC and UVA was set at three different levels in order to provide bookend results. The return values are listed in the table below.

Bookend Simulation	**DOC (mg/L)**	**UVA (cm^{-1})**
Low	6	0.289
Middle	15	0.686
High	30	1.348

Results

Results for the base and plan were compared with each other and with the water quality constraints defined in the Delta Wetlands Water Quality Management Plan (WQMP). Output results were given at four urban intake locations: Old River at Rock Slough, Old River at Los Vaqueros Intake, the intake for the State Water Project and the Intake for the Central Valley Project. Listed below are the major findings.

- ♦ The DSM2 EC simulations, which used the DWRSIM 771 hydrology, gave results that exceeded the Rock Slough Chloride standard for both base and plan conditions during most winters in the 16-year simulation period. Therefore the modeled EC and the calculated TTHM and BRM at the urban intakes is suspect for the Delta Wetlands Alternative and should not be analyzed in an absolute sense.
- ♦ There was little difference in modeled EC between the base and plan conditions.
- ♦ Agricultural returns for the project islands in the base condition have a very small effect on DOC at urban intake locations.
- ♦ DOC results from the DSM2 base case frequently exceeded the 4-mg/L DOC water quality constraint during the spring runoff periods.
- ♦ Results for the simulations with the mid and high DOC releases from the project islands exceeded the 4 mg/l DOC water quality constraint at all of the urban intake locations. Water releases typically occurred during the summer.
- ♦ Results from the simulations with the low DOC concentration release from the project islands did not exceed the 1-mg/l increase water quality constraint but approached it at the Los Vaqueros intake on Old River.
- ♦ The long-term DOC trend results showed that the low DOC concentration release decreased the DOC mass loading at all four urban intake locations. Results from the high and mid DOC concentration releases exceeded the WQMP 5% increase in DOC mass loading limit.
- ♦ Output for UVA showed trends similar to those discussed above for DOC.

TO: Tara Smith
FROM: Michael Mierzwa
DATE: August 26, 2001
RE: Delta Wetlands Preliminary DSM2 Studies

1. Introduction

Delta Wetlands proposes to convert two Delta islands, Bacon Island and Webb Tract, into reservoirs. Both islands would be used to store water during surplus flow periods. Later this water would be released for export enhancement or to meet Delta flow/water quality requirements.

This study uses the DWRSIM 771 existing condition hydrology as the input for a series of DSM2-HYDRO and QUAL 16-year planning studies. This study ran from 1975 – 1991. This hydrology was used by Jones and Stokes in their analysis for Delta Wetlands and is the basis of the Delta Wetlands Environmental Impact Report (EIR). This study is based on the most recent version of the DSM2 geometry, and also makes use of QUAL's ability to model multiple water quality constituents. In addition to the traditional EC modeling, QUAL was used to simulate dissolved organic carbon (DOC) and ultraviolet absorbance at 254 nm (UVA) impacts due to the operation of the two island reservoirs.

This report includes the descriptions of the two scenarios (a base case and an alternative based on the Delta Wetlands project) and the results of these DSM2 simulations at M&I locations. The operation (flow into and out of the island reservoirs) was provided by David Forkel of Delta Wetlands (2001a). The physical specification for the Delta Wetland islands is based on the Delta Wetlands EIR. A brief discussion of the DWR-Municipal Water Quality Investigations (MWQI) data that were used as the boundary conditions for the QUAL DOC and UVA simulations is also provided.

2. Description of Scenarios

The two different scenarios were based on the DWRSIM 771 existing condition hydrology. The base case simulated the Delta without the operations of the proposed Delta Wetlands project. The Delta Wetlands alternative included the proposed operations of Bacon Island and Webb Tract, but did not account for the changes in land use of the two proposed habitat islands. Brief summaries of both scenarios are described below in Table 1, followed by more detailed descriptions of these assumptions.

Table 1: Summary of Planning Scenarios.

	Base: No Action	*Alternative: Delta Wetlands Operations*
Project Islands	No.	Yes. (Bacon Island and Webb Tract.)
Habitat Islands	No.	No.
Boundary Flows	DWRSIM 771.	DWRSIM 771.
Boundary Stage	25-hour Repeating Tide.	25-hour Repeating Tide.
Martinez EC	ANN w/ Net Delta Outflow.	ANN w/ modified Net Delta Outflow.
Rim Boundary EC	DWRSIM 771.	DWRSIM 771.
Island Diversions	Historical DICU.	Modified DICU.
Island Return Flows	Historical DICU.	Modified DICU.
Island Seepage	Historical DICU.	Historical DICU.
Martinez Boundary DOC / UVA	N/A	N/A
Rim Boundary DOC / UVA	MWQI data.	MWQI data.
Island EC	Historical DICU.	Historical DICU. DSM2 mixed and stored EC in Project reservoirs.
Island DOC / UVA	MWQI data.	MWQI data. Three bookend measurements for Project reservoirs.

2.1. No Action (Base Case):

The DWRSIM 771 existing conditions study was used to provide the rim boundary flows and exports. Gate and barrier configurations were designed to account for the proposed operation schedule for the South Delta Permanent Barriers (which include Old River at Head, Old River at Tracy, Middle River, and Grant Line Canal). The Suisun Marsh Salinity Control Gate and Clifton Court Forebay Gates were both operated according to previous DSM2 planning studies that used the DWRSIM 771 existing conditions study as a base case.

Historical DSM2 Delta Island Consumptive Use (DICU) data were used for all the HYDRO simulations and the QUAL EC simulation. Martinez EC data were generated using an artificial neural network (ANN) and Net Delta Outflow. DWR-MWQI observations were used to create synthetic time series for DOC and UVA (see Section 3.6) at the following rim boundaries: San Joaquin River, Sacramento River, and the Eastside streams. The flux of DOC and UVA from the downstream boundary at Martinez (the sea) was considered insignificant. Details on the development of agricultural return DOC and UVA data for DSM2 based on the MWQI observations is described in the report *Revision of Representative Delta Island Return Flow Quality for DSM2 and DICU Model Runs* (Dec. 2000) as prepared by Marvin Jung and Associates, Inc.

2.2. Delta Wetlands Operation (Alternative 1):

Jones and Stokes used the DWRSIM 771 existing conditions study to create a preliminary schedule of diversions into and releases out of the two proposed Delta Wetlands islands. This schedule did not separate the storage, diversions, and releases between the two islands; however, a simple operating rule was proposed to govern the independent operation of the islands. This proposed set of rules is listed below in Table 2.

Table 2: Proposed Rules of Operation.

Filling (Diversions to Islands)	Fill Bacon Island first, then fill Webb Tract.
Emptying (Releases from Islands)	Empty Bacon Island first, then empty Webb Tract.

Using the above operation rules and the target monthly storage for the project reservoirs provided by Jones and Stokes, the diversions and releases for each island as well as each pump were separated for use in DSM2-HYDRO. The result of these operation rules is that each island fills and empties at different times and for different amounts. The combined diversions for both pumps at each island are shown below in Figure 1. The releases for each island are shown below in Figure 2. The process by which these diversions and releases were calculated is further explained in Appendix A.

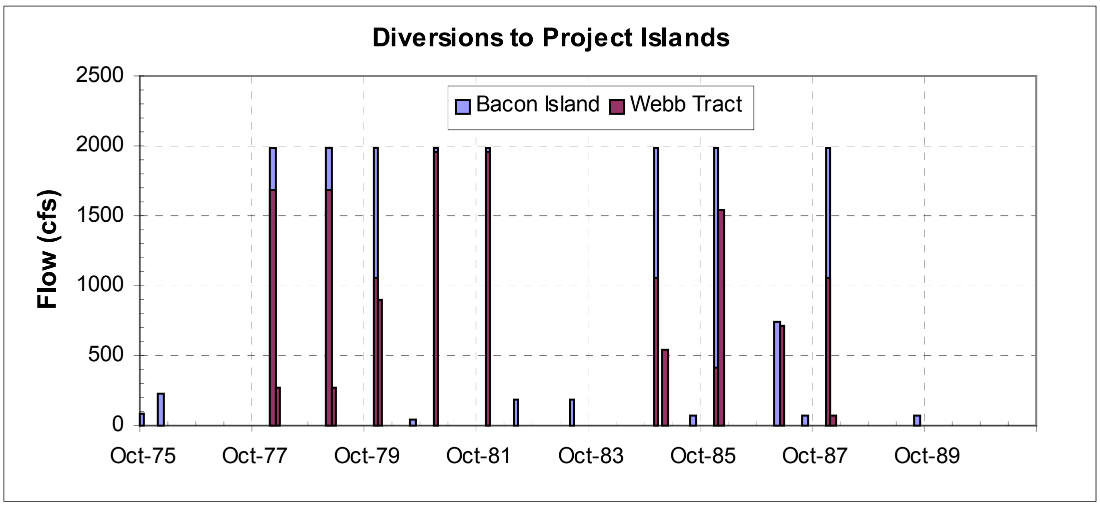


Figure 1: Diversions to Delta Wetlands.

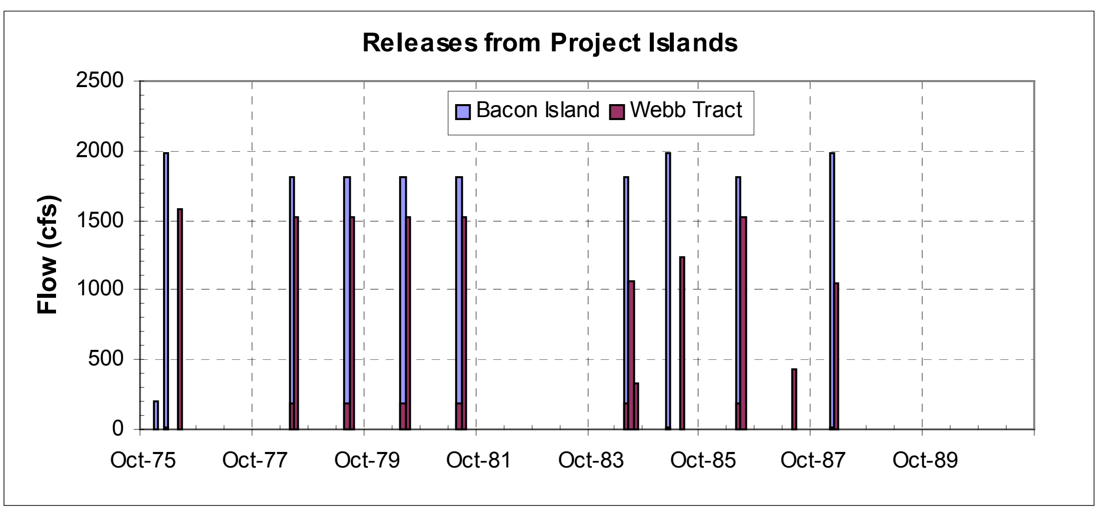


Figure 2: Releases from Delta Wetlands.

The configuration of the project islands as modeled by DSM2 is listed in Table 3. The storage capacity, discharge location, and both intake locations for the project islands determined from the Delta Wetlands EIR. [1] The locations are shown in Figures 3 and 4. According to the operations EIR schedule, water was typically diverted into the islands in the winter on the northern ends of the islands and released back into the Delta in the summer on the southern ends of the islands.

Table 3: DSM2 configuration of Delta Wetlands project islands.

Island	***Storage Capacity (TAF)***	***Discharge Location (Node)***	***Intake Location #1 (Node)***	***Intake Location #2 (Node)***
Bacon Island	120	213	98	128
Webb Tract	118	224	40	103

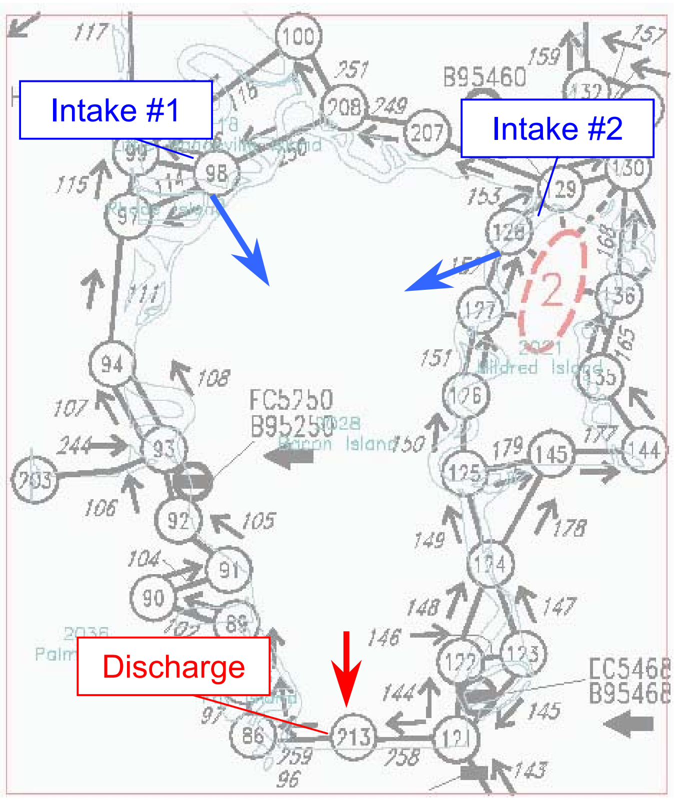


Figure 3: DSM2 Representation of Bacon Island.

[1] The Bacon Island discharge location (node 213) is based on a location determined from a draft EIR from early 2000. This location has been moved to the Middle River in the current EIR. By moving the Bacon Island discharge location away from the Old River, it is expected that the water quality impacts from Bacon Island releases will be reduced at both the Contra Costa Old River and Los Vaqueros intakes. Future DSM2 studies will model the Bacon Island location at a point consistent with the current EIR.

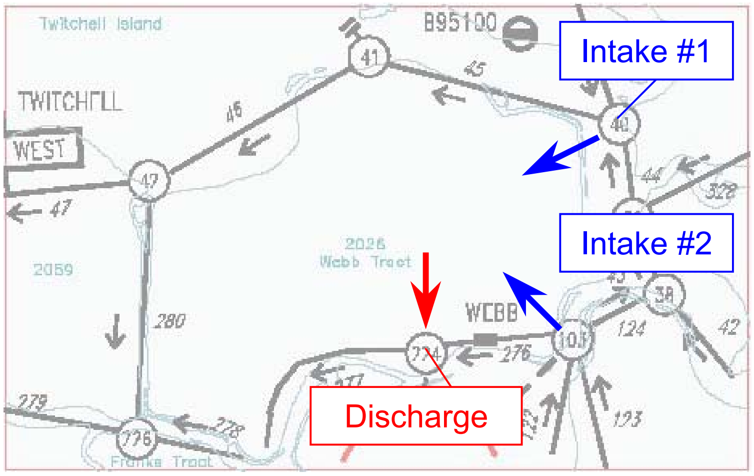


Figure 4: DSM2 Representation of Webb Tract.

The volume of water stored in each island reservoir is a direct function of the amount of water diverted into or released from each island. Volume of a reservoir in DSM2 is the product of the reservoir's surface area and its current stage level. The project island reservoirs were isolated from the Delta channels, thus there was no limit to the stage in either reservoir. In order to prevent drying up of the island reservoirs 5 ft of water was assumed to be present on both islands at the beginning of the simulation.[2] This water was considered dead storage and was never released into the Delta. Although the initial concentration of this dead storage is 0 umhos/cm, inchannel water was diverted into Bacon Island and later released several times during the DSM2 spin-up period in 1974 and 1975. Through this activity the dead storage EC concentration in Bacon Island was 161 umhos/cm at the start of the DSM2 simulation.

Water quality from the two Delta Wetland island reservoirs was modeled two different ways using DSM2. These two different approaches are described below.

For the QUAL EC simulations the reservoirs were isolated from the Delta channels as described above and flow between the surrounding channels and the project islands were regulated in DSM2 by a direct "object-to-object" transfer. When water was diverted into the islands, this object-to-object transfer moved water from both of the intake nodes for the islands being filled into the reservoir. This process was reversed in accordance with the release schedule except that water was then discharged at the discharge locations listed in Table 3.

This process allowed QUAL to automatically mix incoming EC concentrations from the nearby channels with the EC already present in the reservoirs; thus the water released from the reservoirs would better represent the mixed water quality of the water stored in the reservoirs. The EC concentrations of the island reservoirs only changed when new

[2] The choice of 5 ft of depth was chosen as a preliminary starting depth in the EC simulations in order to prevent DSM2 from drying up. DSM2 does not support the wetting and drying of channels or reservoirs. Future DSM2 studies will use a smaller depth for the reservoir dead storage.

water was transferred into the islands, not when water exited the islands. This process is described in greater detail in Section 4.1.

For the QUAL DOC and UVA simulations, these preliminary studies were designed to investigate the impact of different DOC and UVA “bookend” measurements. Instead of using active reservoirs, diversions to the islands were treated as sinks located at the two intake nodes for each island and the releases from the islands were treated as sources located at the discharge locations. Water released back into the Delta through the discharge nodes was given a fixed DOC or UVA concentration depending upon the scenario. A list of DOC and UVA values for both islands is listed below in Table 4.

Table 4: Summary of DOC and UVA Delta Wetlands Operations Values.

Bookend Simulation	***DOC (mg/L)***	***UVA (cm^{-1})***
Low	6	0.289
Middle	15	0.686
High	30	1.348

The UVA measurements were based on the DOC concentrations, using the relation developed in the *Revision of Representative Delta Island Return Flow Quality for DSM2 and DICU Model Run* report (see Equation 1).

$$UVA = 0.02374 + 0.04415 \times DOC \quad \text{[Eqn. 1]}$$

With changes in the land use of the project islands, the diversions and return flows for Bacon Island and Webb Tract were modified using the Delta Island Consumptive Use (DICU) model. DICU computes the consumptive use at each node in DSM2 based on the historical needs for each island or water habitat in the Delta. The diversions and return flows for each island are distributed to different nodes, such that the modeled diversions, return flows, and/or seepage at any one node frequently include the individual contributions from different islands. The contributions from Bacon Island and Webb Tract were removed from all of the nodes surrounding both islands (see Figures 3 and 4). DSM2 mixes return flows with fixed “drainage” water quality measurements at each node. Even though the contributions from the project islands were removed from the intake and release nodes, the diversions and return flows from the neighboring islands could mix with the measurements coming from the island reservoirs. In order to prevent DSM2 from mixing the return flows from these neighboring islands with the fixed bookend concentrations, the diversions and return flows from other islands were relocated from the intake and pump locations listed in Table 3 to nearby nodes.

Since seepage in DSM2 represents the amount of water that comes from the Delta channels to the islands, it was not modified for either scenario.

3. Simulation Inputs

3.1. Delta Cross Channel

The position of the Delta Cross Channel was predetermined by the DWRSIM 771 existing conditions study. For most years, the Delta Cross Channel was closed except during the summer months Jun. – Sep. when flow at Freeport (as modeled by DWRSIM) was less than 23,000 cfs. In some wet years, such as 1982 and 1983 the Delta Cross Channel was also closed during some of these months due to high flow conditions.

3.2. Flow

Rim flows, exports, and diversions not covered above in the description of the Delta Wetlands Operation came from the DWRSIM 771 existing conditions study. The rim flows include the Sacramento River, San Joaquin River, and the Yolo Bypass and then a combined parameter representing the eastside flows into the Delta. Exports include the State Water Project (SWP), the Central Valley Project (CVP), Vallejo diversions, North Bay Aqueduct diversions, and Contra Costa Canal diversions from Rock Slough. Contra Costa operations on the Old River for the Los Vaqueros reservoir were not available at the time this study was conducted.

The combined SWP and CVP exports are shown in Figure 5 (below) in order to provide a general feel for the amount of water that would be flowing south through the Central Delta over the study period.

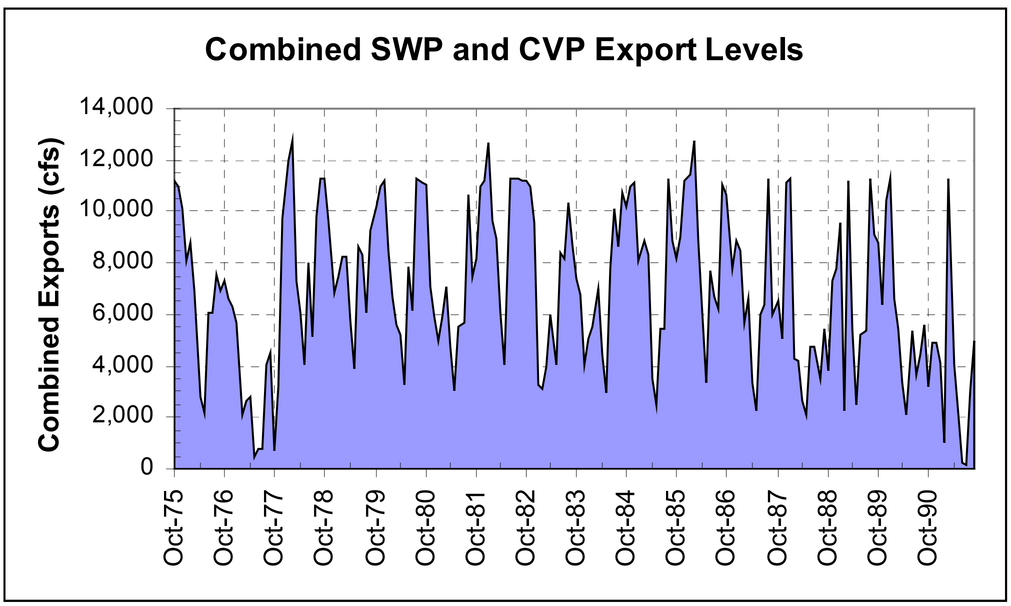


Figure 5: Combined SWP and CVP Export Levels.

3.3. Stage

A repeating tide was used as the downstream boundary condition at Martinez. This tide includes flood / ebb variations, but does not include Spring / Neap variations.

3.4. South Delta Permanent Gates

The proposed future operation of the four South Delta fish and agricultural permanent gates, Old River at Head, Old River at Tracy, Middle River, and Grant Line Canal barriers, was used in this study. When operating, the gates only allowed flow in the upstream direction. Each structure is either installed or removed during one of 13 planning periods, see Figure 6 below. Each month represents one planning period, with the exception of April, which is divided into two planning periods. This was done so the gates could be installed in the middle of the month, per the proposed future operation of the gates.

Barrier	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Old River @ Head												
Old River @ Tracy												
Middle River												
Grant Line Canal												

Figure 6: Schedule of Permanent Barrier Operations.

3.5. Other Gates

The Suisun Marsh Salinity Control Gate was operated October through May of each year. The Clifton Court Forebay Gates were operated based on a schedule created for prior DSM2 planning runs that used the same DWRSIM 771 study as input. The Forebay Gate schedule would open the gates at different times based on one of three priorities. These priorities optimize the intake of water into the Forebay while offering increasing levels of protection to the water levels in the South Delta. A complete description of these priorities and their implementation in DSM2 can be found in *Status Report on Technical Studies for CALFED Water Management Planning* (Jul. 1999).

3.6. Quality

Water quality inputs were applied both at the external boundaries and at Delta interior locations through Delta Island Consumptive Use (DICU). The sources and nature of these data are discussed below.

3.6.1. EC

As discussed above in the description of the base case, the Martinez downstream boundary EC was generated using an ANN with Net Delta Outflow as the input. Kristof coefficients were used to convert daily EC into hourly values for use in QUAL.

The rim flow boundaries for the Sacramento River, Yolo Bypass, and eastside streams were all given fixed EC concentrations of 125, 150, and 125 umhos/cm respectively.

Standard DICU data developed from DWR Delta Modeling's DICU model were used to represent the quality of water draining off the Delta islands. For the base case all of the standard DICU node locations were used. For the alternate scenario some of the nodes surrounding Bacon Island and Webb Tract were modified (see section 2.2 for a detailed description of how this was done) in order to account for the change in use of these two islands.

3.6.2. DOC

Based on monthly dissolved organic carbon observations from DWR MWQI, time series of monthly average DOC were created for the Sacramento River, San Joaquin River, and eastside streams (see Figure 7). The Sacramento River data were based on Green's Landing observations. Vernalis observations were used for the San Joaquin River data. The eastside stream data were based on American River observations. These three time series were applied as the boundary conditions. It was assumed that the amount of DOC at the downstream Martinez boundary was negligible.

Bookend values were used to represent the DOC coming off the project islands. Table 5 (located above) summarizes these bookends.

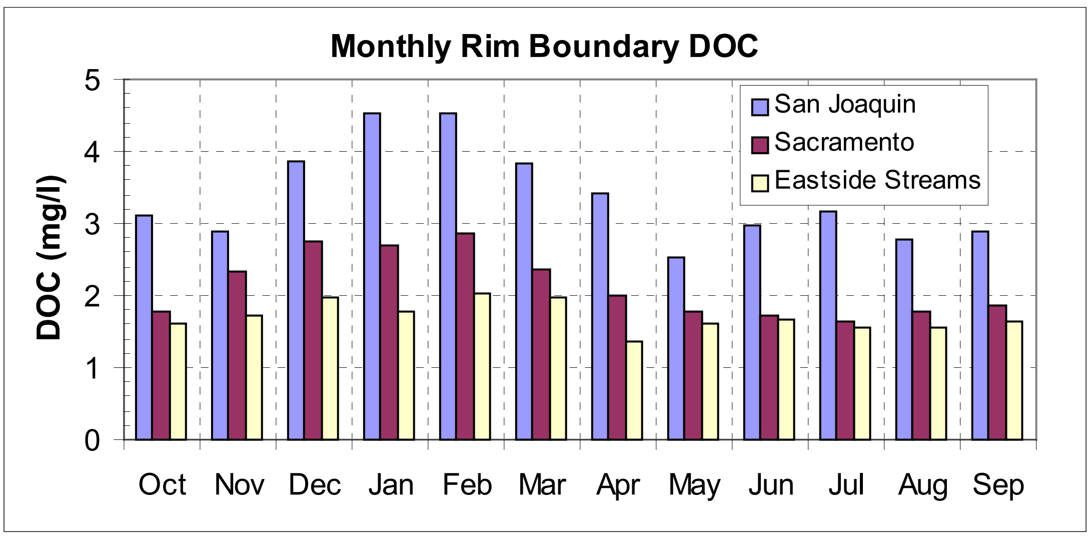


Figure 7: Monthly Averaged DOC Boundary Conditions.

DICU data developed as part of the DWR MWQI studies were used to represent the DOC (mg/l) draining off the Delta islands (see Jung, 2000). Three different ranges of DOC returns were used in the DOC DICU data. Figure 8 represents the DOC values as modeled in DSM2 for the three different ranges. As illustrated in Figure 8, high range DOC is associated with DOC releases that peak out above 30 mg/l. Similarly, the low range DOC is used for islands that were found to have low DOC releases. For the base case, all of the historic DICU agricultural diversions and return flows were used. Some of the agricultural diversions and return flows in the alternate scenario were modified as described in Section 2.2.

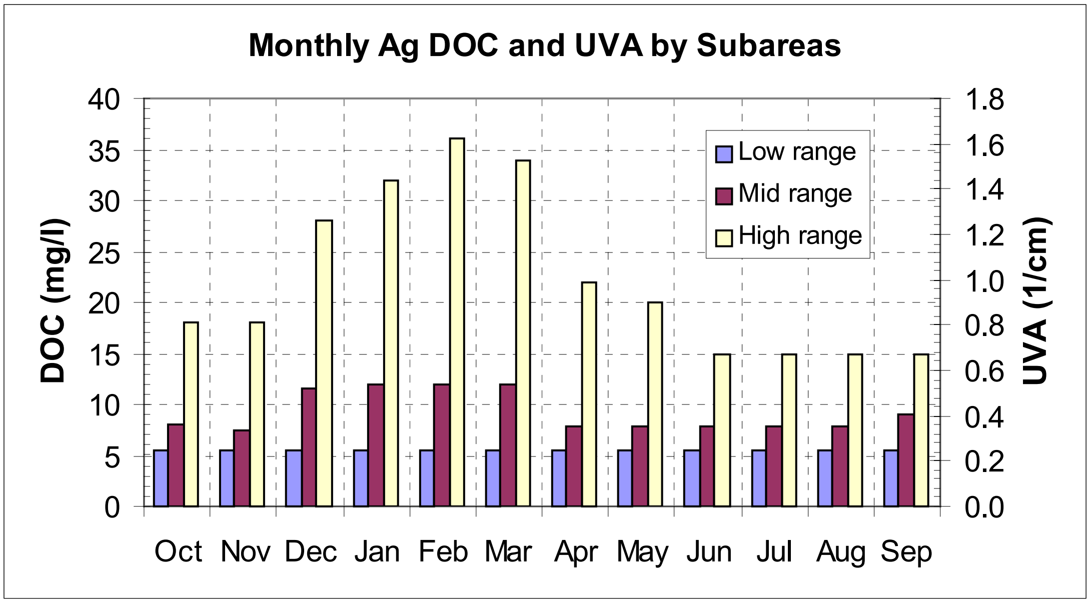


Figure 8: Monthly Averaged DOC and UVA from Agricultural Returns.

3.6.3. UVA

Based on monthly UVA-254 observations from DWR MWQI, time series of monthly average UVA were created for the Sacramento River, San Joaquin River, and eastside streams (see Figure 9). These three time series were applied as the boundary conditions. Again, the UVA-254 value at the downstream Martinez boundary was considered negligible.

Bookend values were used to represent the UVA coming off the project islands. Table 5 (located above) summarizes these bookends. These bookends were calculated using the relationship (Equation 1) described in Section 2.2 developed by Jung.

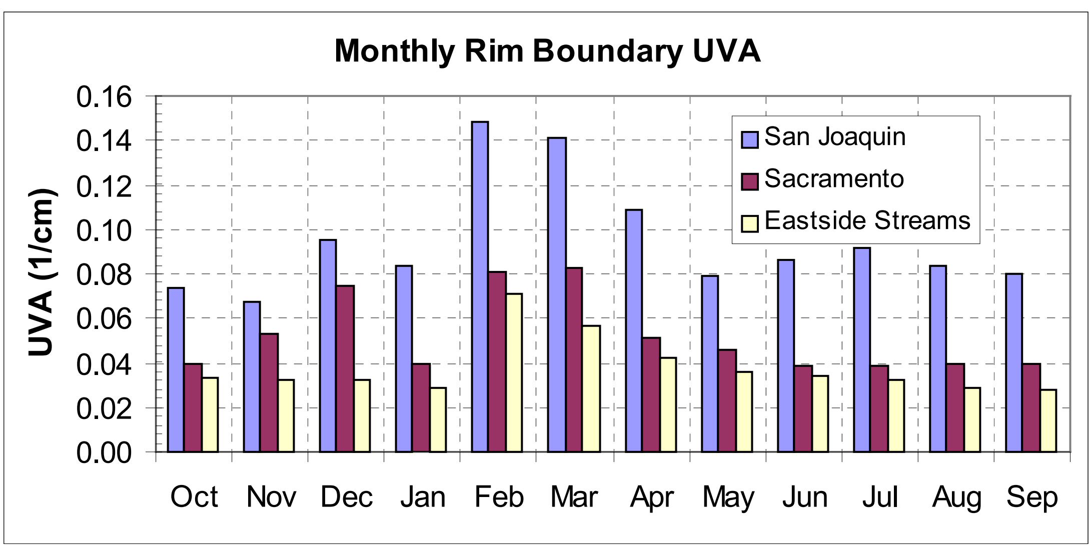


Figure 9: Monthly Averaged UVA Boundary Conditions.

DICU data developed as part of the DWR MWQI studies were used to represent the water quality draining off the Delta islands (see Jung, 2000). Three different ranges of UVA returns were used in the UVA DICU data. The values of these ranges are illustrated in Figure 8. The values were calculated by converting DOC to UVA using Equation 1. For the base case, all of the standard DICU agricultural diversions and return flows were used. Some of the agricultural diversions and return flows in the alternate scenario were modified as described in Section 2.2.

3.6.4. Initial Conditions (Cold Start)

DSM2 planning studies cover a 16-year period from Oct. 1975 to Sep. 1991. Unlike HYDRO, QUAL requires a much longer start-up period. In the case of planning studies, no assumption is made about the initial water quality conditions in the Delta; thus an extra year is run in order to simulate the mixing of the delta. This is called a cold start routine. Both HYDRO and QUAL are run for this extra year, but the results are disregarded during this cold start period.

4. Results

This report discusses three water quality constituents, electrical conductivity (EC), dissolved organic carbons (DOC), and ultraviolet absorbance at 254 nm (UVA).

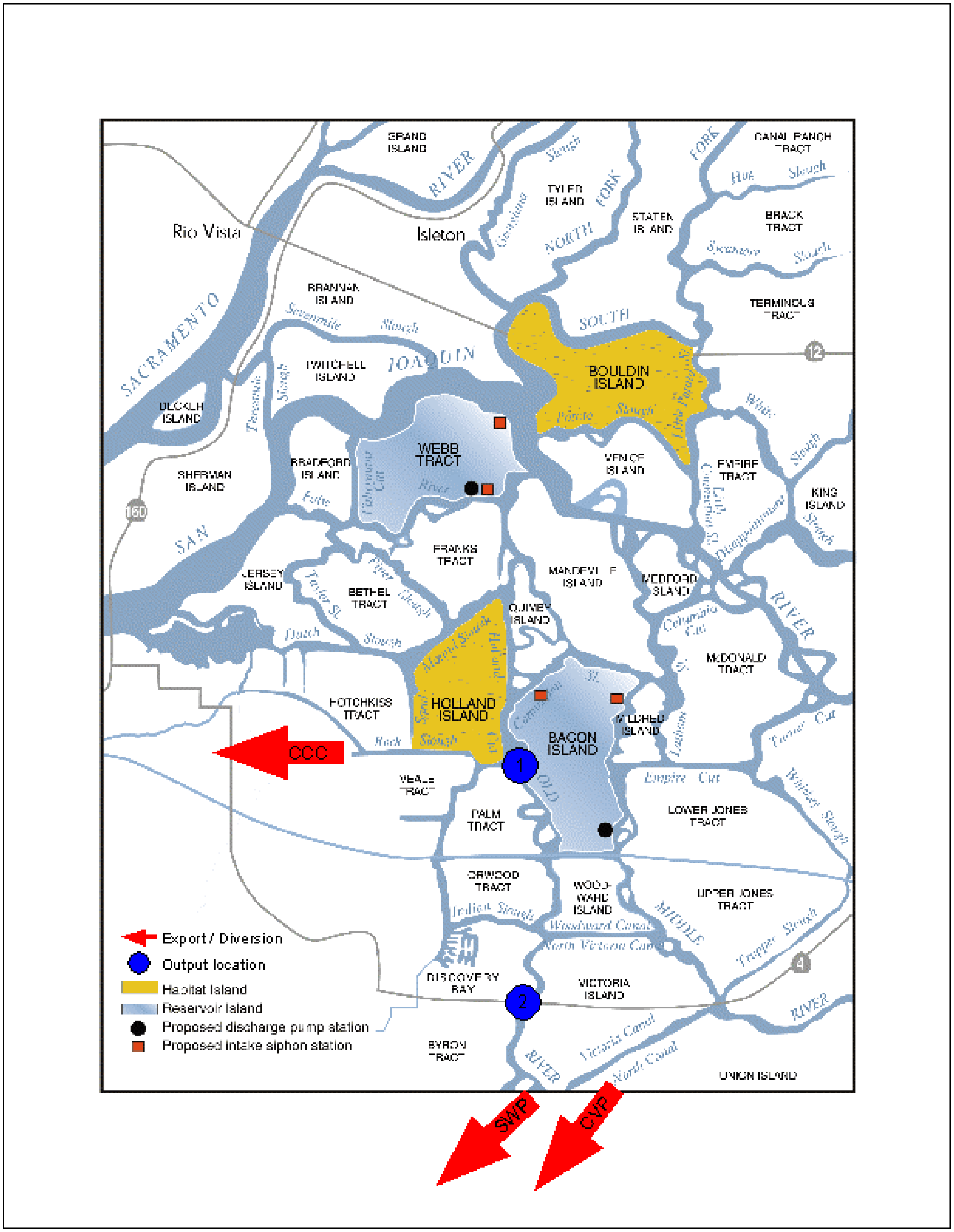


Figure 10: Location of Delta Wetland Project Islands and Output Locations.

Modeled water quality at four export / diversion facilities are shown below for the entire planning period (1975 – 1991): Contra Costa's Rock Slough intake near the Old River, Contra Costa's Los Vaqueros intake on the Old River, the SWP and CVP intakes at

Banks and Tracy. The actual output locations for Contra Costa's Rock Slough (location #1) and Contra Costa's Los Vaqueros (location #2) intakes were along the Old River, as are shown above in Figure 10. [NOTE: The habitat islands shown in Figure 10 were treated as normal Delta islands in DSM2.]

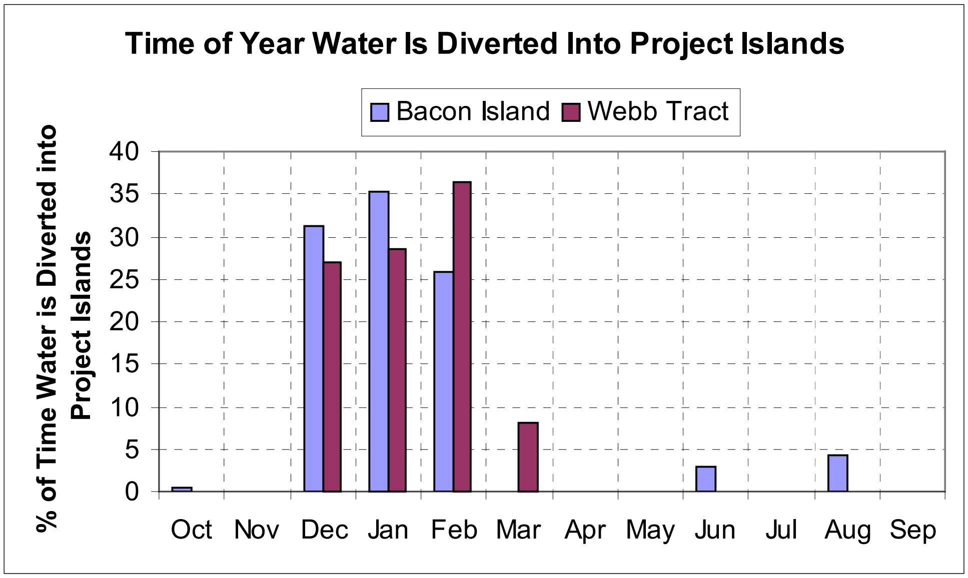


Figure 11: Time of Year Water is Diverted to Project Islands.

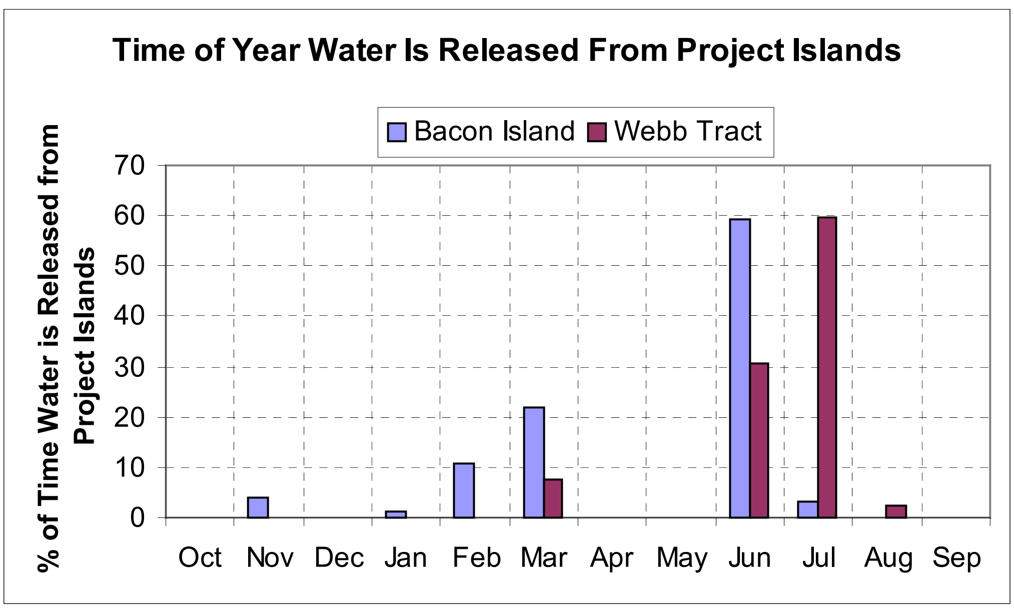


Figure 12: Time of Year Water is Released from Project Islands.

The percentage of the time of year water was diverted to and later released from the project islands for the entire study period is shown in Figures 11 and 12. Generally the islands were filled in the winter months (Dec., Jan., and Feb.) and emptied in the summer months (Jun. and Jul.). The timing of the combined SWP and CVP exports were determined by the DWRSIM 771 study and are shown in Figure 5.

4.1. EC

As described above in Table 3 (see Section 2.2), two reservoirs were created to simulate EC coming from the two project islands: Bacon Island and Webb Tract. These reservoirs were connected to the Delta in DSM2 by using object to object transfers. This technique controlled when water would be added to or removed from the reservoirs. It also allowed for the intake points to be separated from the discharge location.

Since the water quality of the reservoir islands is a function of the water quality around the intakes and the current water quality in each island reservoir, QUAL was able to store the water and account for changes in water quality due to mixing, as shown in Equation 2. The only time water quality in the islands would change was when water was added, which can be seen in Figures 13 and 14.

$$C_{new} = \frac{C_{\inf lows} V_{\inf lows} + C_{island} V_{island}}{V_{\inf lows} + V_{island}} \qquad \text{[Eqn. 2]}$$

If the EC concentration of the water at the intakes was lower than the EC levels inside the island reservoir, then the inflows would reduce the island EC concentration. If the EC concentration of the water at the intakes was higher than then the EC levels inside the island, then the inflows would increase the island EC concentration.

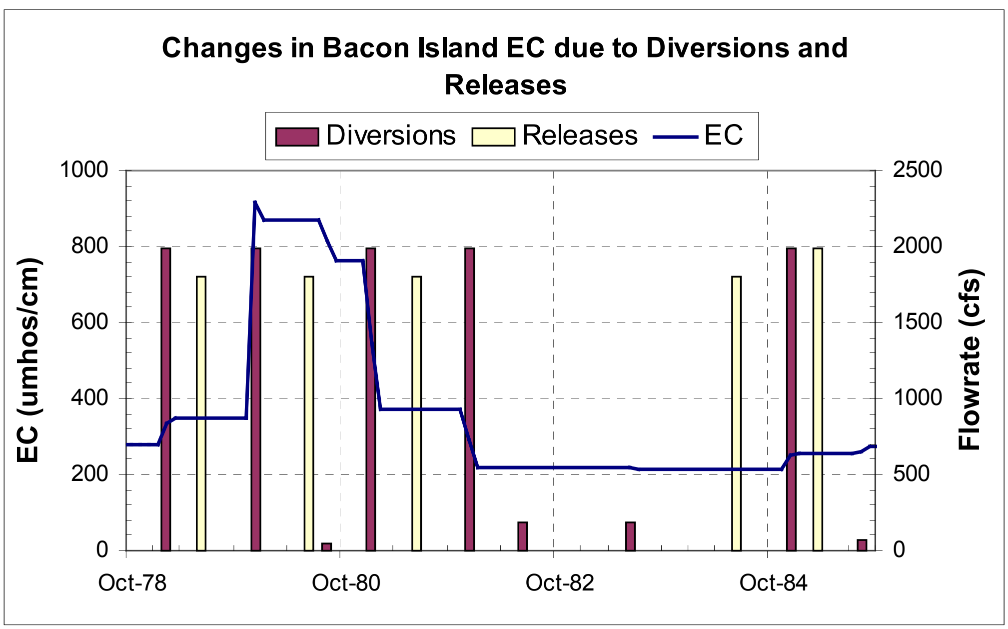


Figure 13: EC (umhos/cm) in Bacon Island.

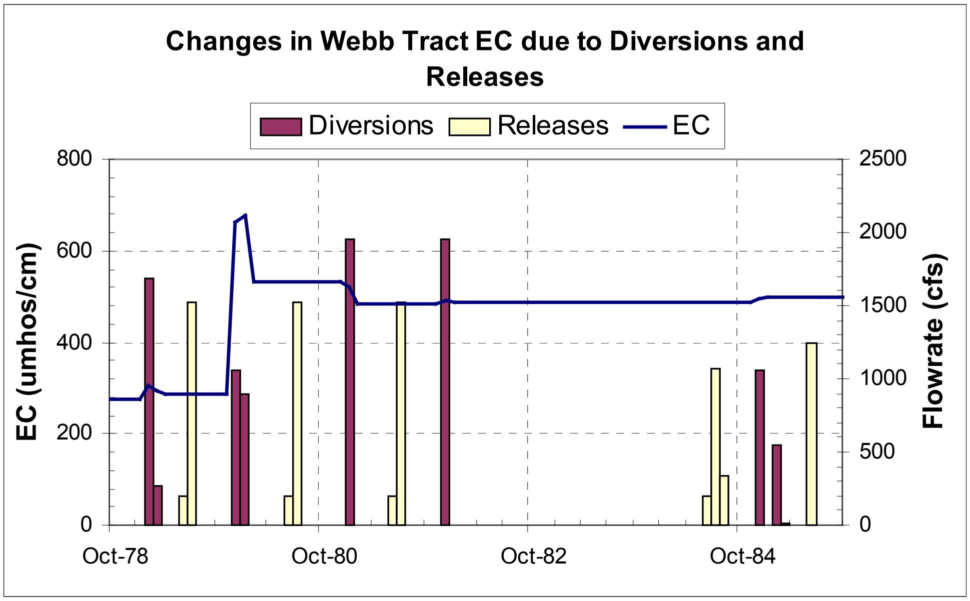


Figure 14: EC (umhos/cm) in Webb Tract.

The act of diverting water into and releasing it from the project islands only had minor changes on the Net Delta Outflow. As shown above in Figure 1, the combined amount of diversion to the islands never exceeded 4,000 cfs. Similarly, the releases (see Figure 2) never exceeded 2,000 cfs. The changes to Net Delta Outflow were fairly small, as is shown below in Figure 15.

Since the EC at downstream boundary (Martinez) was generated using an ANN with Net Delta Outflow as the input, a new EC boundary condition was calculated based on changes to the Net Delta Outflow. The modeled EC for both the base and alternative scenarios is shown below in Figure 16. These differences were fairly small.

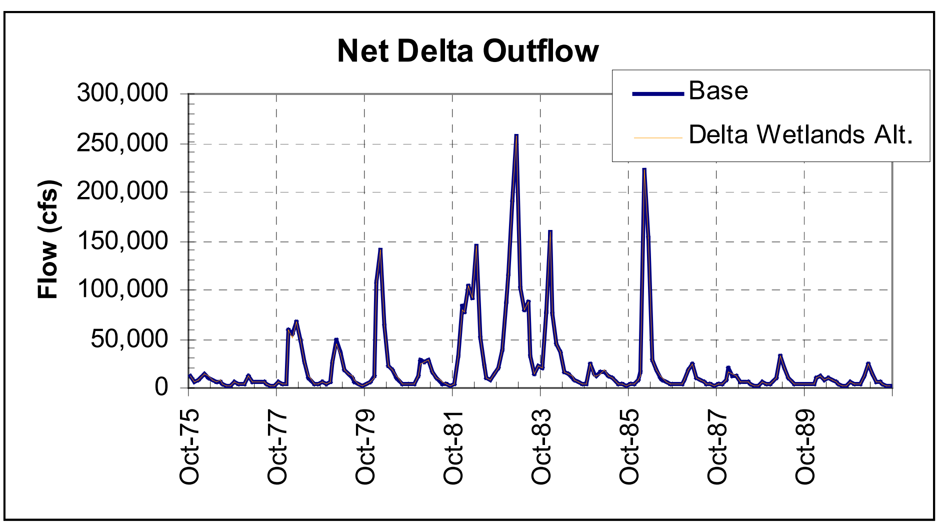


Figure 15: Net Delta Outflow.

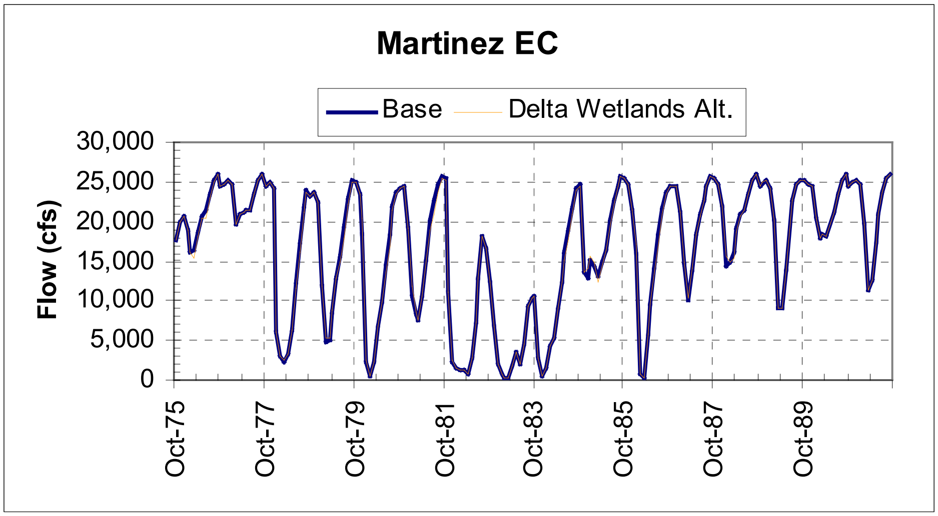


Figure 16: Martinez EC (umhos/cm).

Discharges from the islands did not change the water quality of the reservoirs (see Figures 13 and 14) and had little impact on the EC concentration in the Delta itself. The impacts of the releases from both project islands are compared to the base case scenario in Figures 17 - 28.

The EC values shown in Figures 17, 20, 23, and 26 are monthly averages that were computed using the daily EC values modeled by DSM2. It is important to remember that DWRSIM hydrology was based on a monthly time step, and that the downstream tidal boundary was represented by a repeating tide, which does not include the Spring / Neap cycle that would normally be associated with the draining and filling of the Delta. A chloride standard of 225 mg/l for Rock Slough is shown on all four figures. This standard was converted from Chloride to EC using the relationship shown in Equation 3. Traditionally, a 225 mg/l Cl standard at Rock Slough is used to account for the fact that the 250 mg/l daily standard is being modeled in monthly time steps by DWRSIM and DSM2. In this particular study, the WQMP calls for 90% of the same daily standard (which just happens to be 225 mg/l).

$$EC_{Rock\ Slough} = \frac{Chloride_{Rock\ Slough} + 24}{0.268} \qquad \text{[Eqn. 3]}$$

The Rock Slough Chloride standard was exceeded at all four urban intake locations for both the base and alternative studies. In fact there is little difference in EC between the two studies. However, since this standard was exceeded for even the base case[3], it makes it difficult to evaluate the impact of the Delta Wetlands project operations on the four urban intake locations.

[3] DSM2 base case violations of the Rock Slough chloride standard are caused by the mismatch between the G-Model used by DWRSIM and DSM2. An ANN trained using DSM2 has been incorporated into CALSIM II. When future Delta Wetlands DSM2 studies are based on CALSIM operations, this mismatch should be resolved.

The cumulative distribution function (cdf) of EC for each of the four urban intake locations is shown in Figures 18, 21, 24, and 27. Each cdf curve represents the amount of time that EC is equal to or less than a corresponding EC concentration. For example, the 225 mg/l standard shown in Figure 18 is met approximately 74% of the time for both simulations. These cdfs were calculated based on the frequency histograms for absolute EC for every month of the entire 16-year simulations. Again, there is no significant difference between the base and alternative studies at all four locations.

The WQMP also limits the increase in salinity at any of the urban intakes due to project operation to 10 mg/l chloride (which is equivalent to 37 umhos/cm). The cdf for the change (measured as alternative – base case EC) in EC at each location is shown in Figures 19, 22, 25, and 28. These figures illustrate that over the study period that the overall changes in EC tended to be between –50 and 50 umhos/cm. These plots are useful in measuring the impact of the Delta Wetlands project operations on the four urban intake locations.

A summary of the increase in salinity at the urban intakes is shown below in Table 5. The project islands resulted in increases above the WQMP 10 mg/l chloride standard between 5-6% of the time at both the Old River at Rock Slough and Old River at the Los Vaqueros Reservoir intakes.

Table 5: Percent of time that the change in Cl is larger than 10 mg/l.

Location	*% Exceedence*
Old River at Rock Slough	6
Old River at Los Vaqueros intake	5
State Water Project	3
Central Valley Project	3

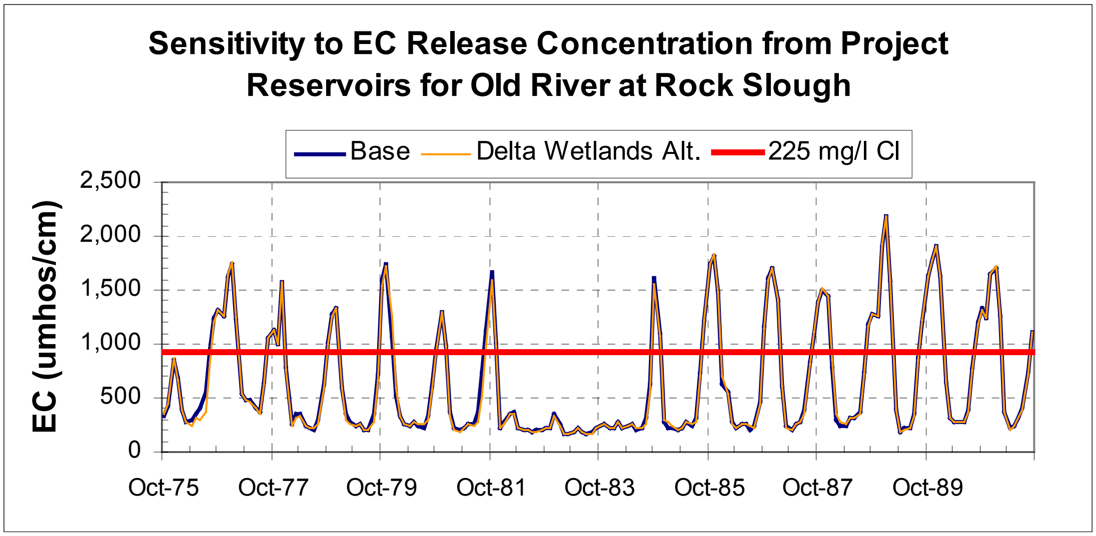


Figure 17: Sensitivity to EC Release Concentration from Project Reservoirs for Old River at Rock Slough.

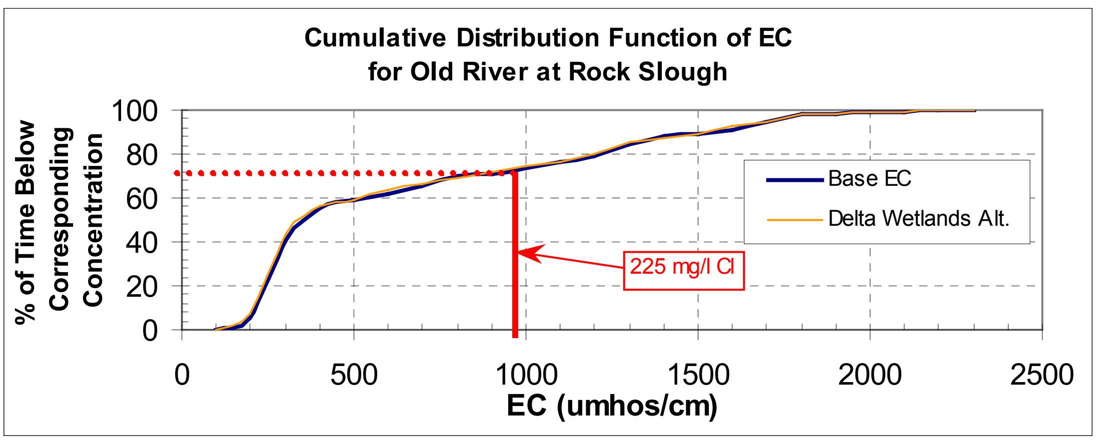


Figure 18: Cumulative Distribution Function of EC for Old River at Rock Slough.

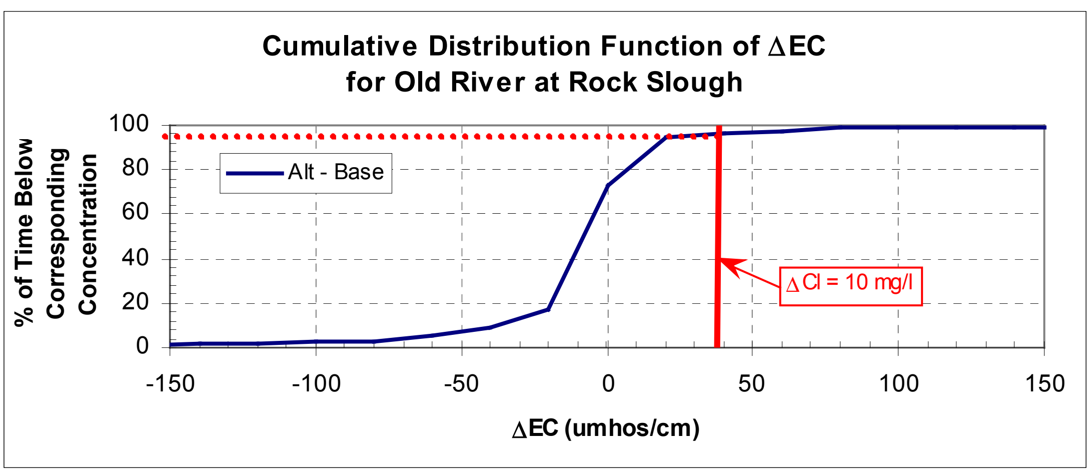


Figure 19: Cumulative Distribution Function of ΔEC for Old River at Rock Slough.

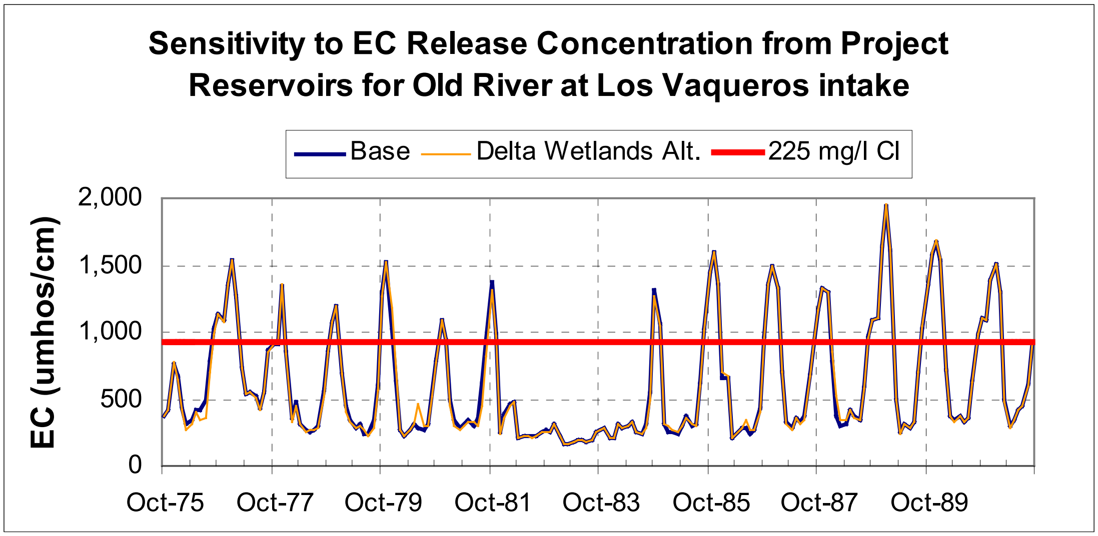


Figure 20: Sensitivity to EC Release Concentration from Project Reservoirs for Old River at Los Vaqueros.

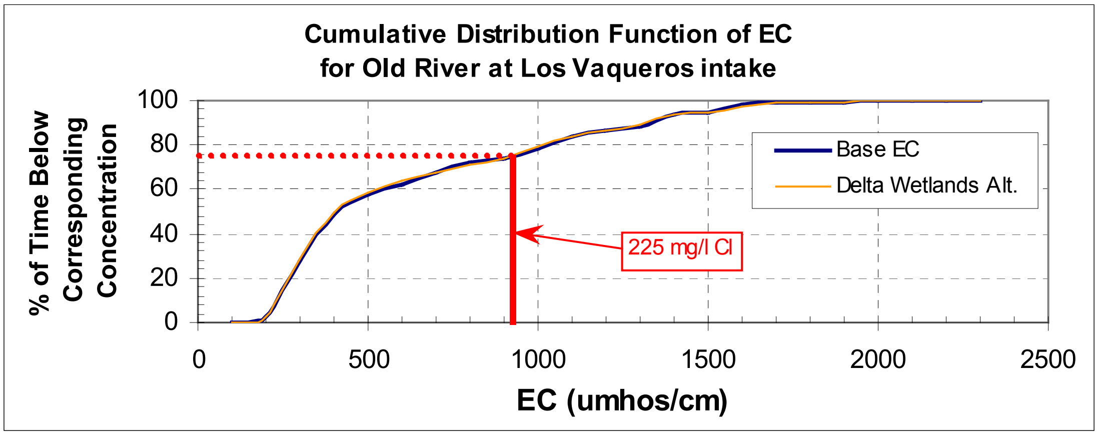


Figure 21: Cumulative Distribution Function of EC for Old River at Los Vaqueros.

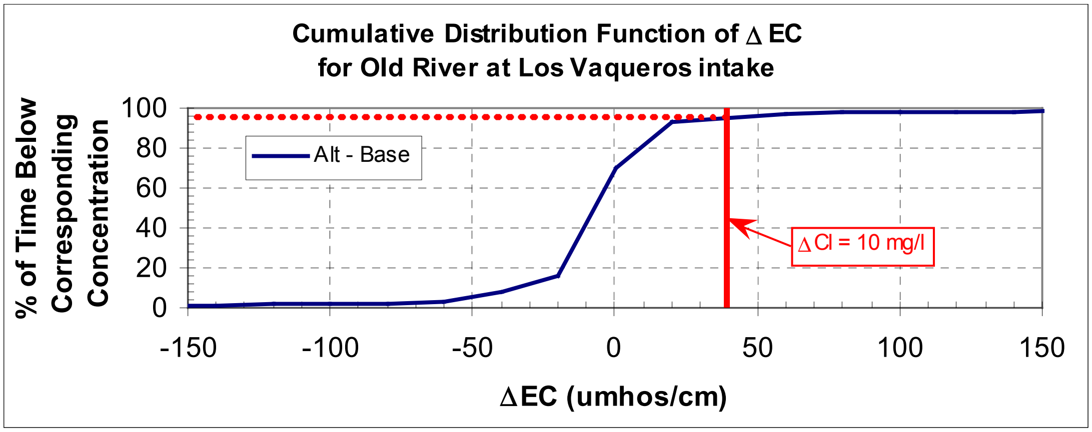


Figure 22: Cumulative Distribution Function of ΔEC for Old River at Los Vaqueros.

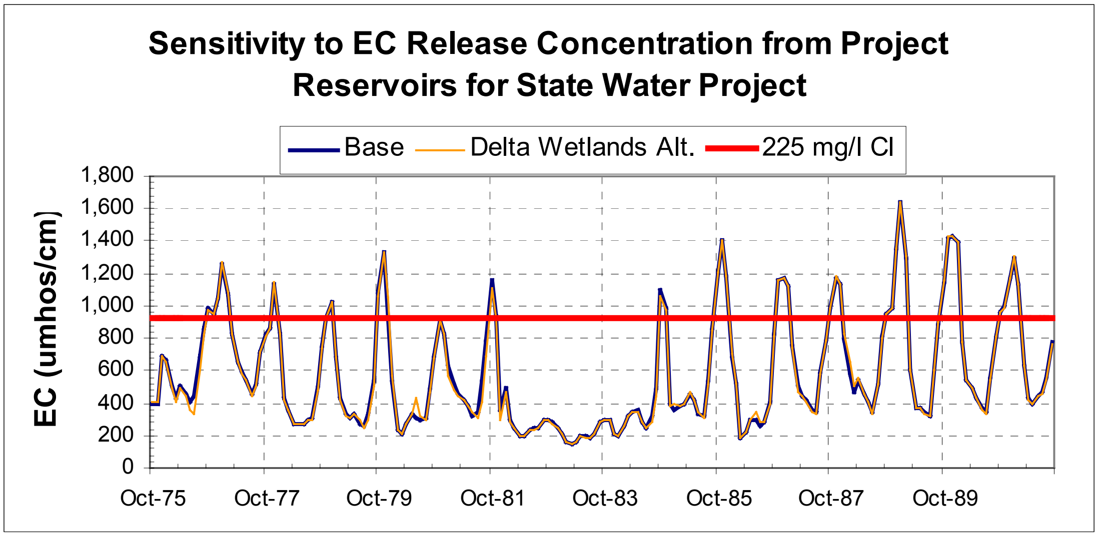


Figure 23: Sensitivity to EC Release Concentration from Project Reservoirs for State Water Project.

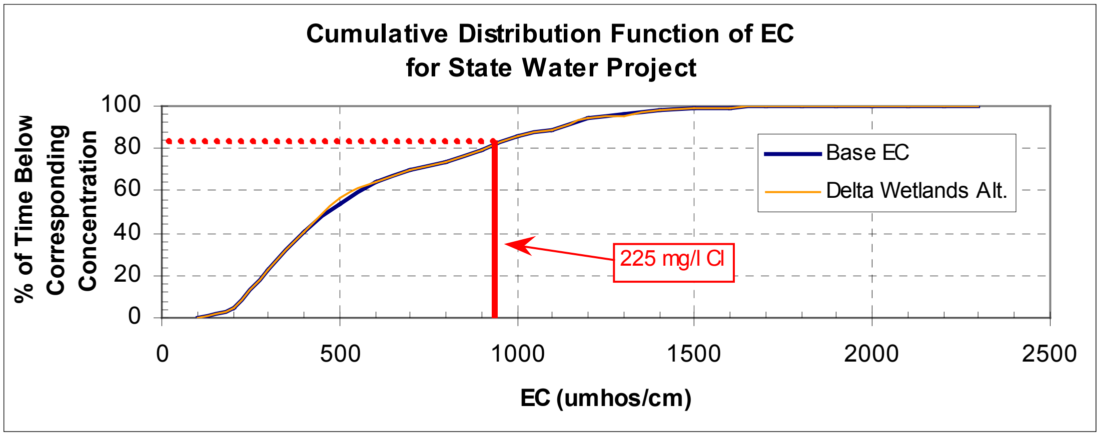


Figure 24: Cumulative Distribution Function of EC for State Water Project.

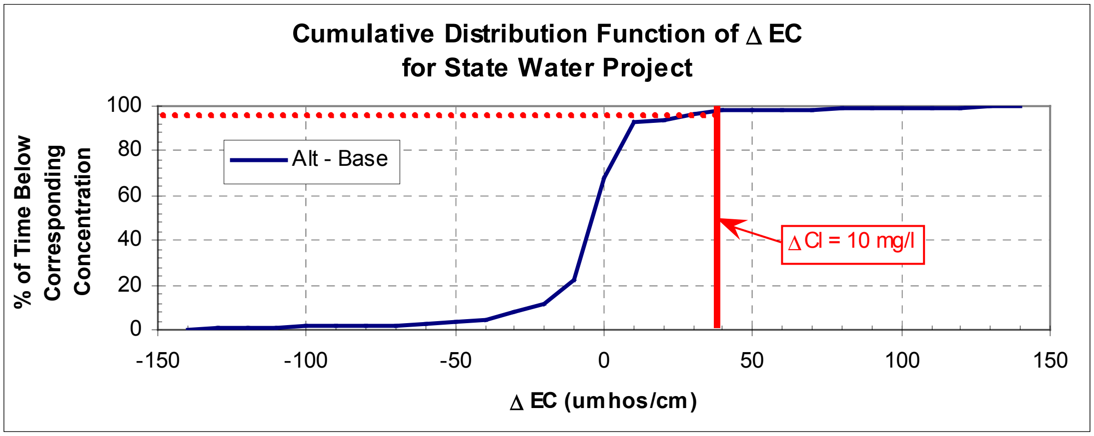


Figure 25: Cumulative Distribution Function of ΔEC for State Water Project.

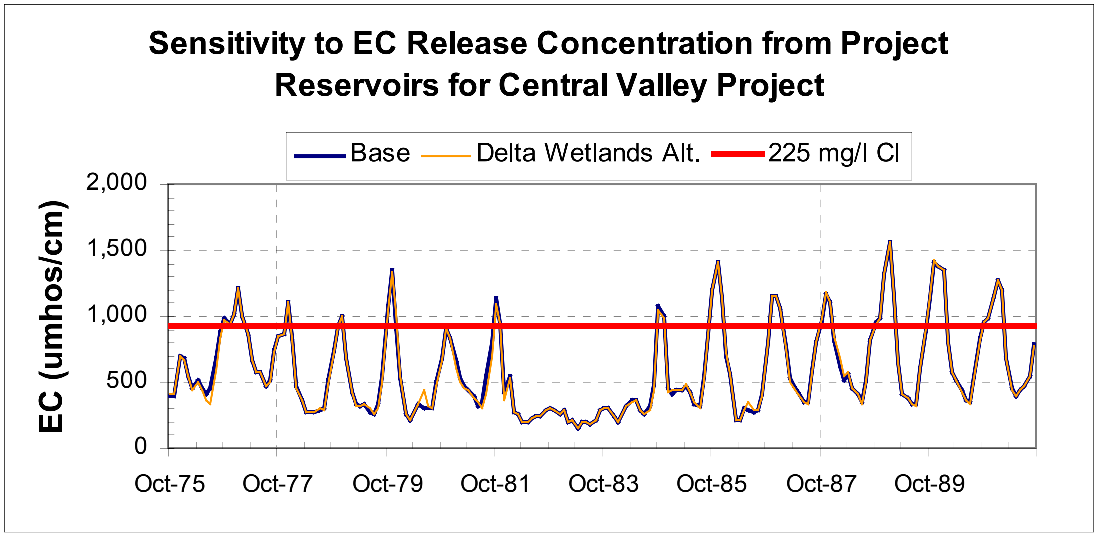


Figure 26: Sensitivity to EC Release Concentration from Project Reservoirs for Central Valley Project.

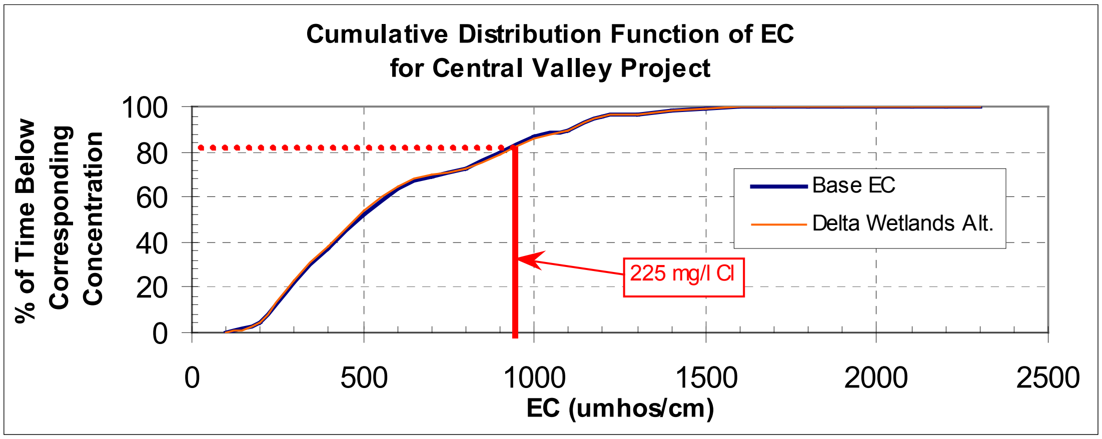


Figure 27: Cumulative Distribution Function of EC for Central Valley Project.

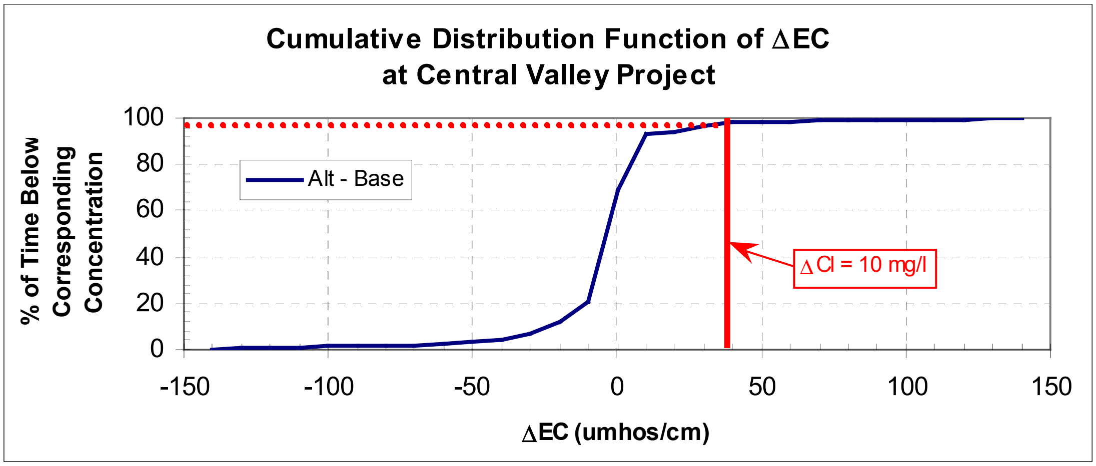


Figure 28: Cumulative Distribution Function of ΔEC for Central Valley Project.

4.2. DOC

Three different bookend DOC simulations were run to create bookends for the impacts on DOC due to the operation of the Delta Wetlands project. The level of the DOC releases for each of these simulations is described above in Table 4 (see Section 2.2).

It was not necessary to model the two islands as reservoirs (as was done for EC modeling). The diversions into the reservoirs were treated as standard diversions. Water was removed from the Delta at the planned intake locations. Similarly, the releases from the islands were treated as rim or return flows at the planned discharge locations. Fixed DOC concentrations were assigned to these releases. The DOC from these releases would then mix with the DOC present in the Delta that came from both the rim boundaries and DICU data (as described above in the simulation inputs section).

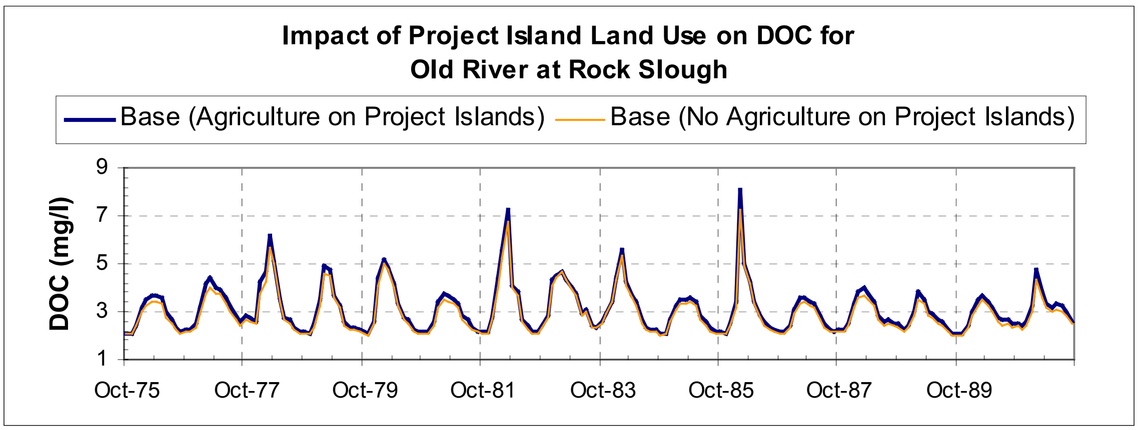


Figure 29: Effect of DICU around the Delta Wetlands Islands on Old River at Rock Slough.

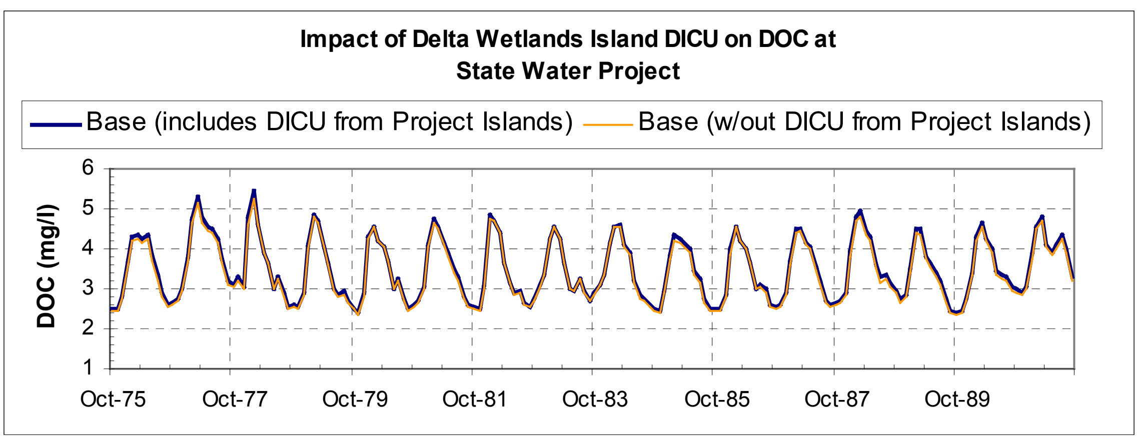


Figure 30: Effect of DICU around the Delta Wetlands Islands at the SWP.

In order to assess the effect of changing the land use on the project islands independently of the planned Delta Wetlands Project operations, an additional scenario, where only the consumptive use for Bacon Island and Webb Tract was changed, was run. This difference is referred to as the *DOC ag credit*. As shown in Figures 29 and 30, the *DOC ag credit* at both Old River at Rock Slough and at the State Water Project Tracy Pumping plant is relatively small.

Figures 31, 34, 37, and 40 illustrate the sensitivity to DOC release concentrations at each of the four urban intake locations: Old River at Rock Slough, Old River at the Los Vaqueros intake, the State Water Project intake at Banks Pumping Plant, and the Central Valley Project intake at Tracy. The 4 mg/l DOC standard described in the Delta Wetlands Water Quality Management Plan (WQMP) is shown on these figures.

The base case DOC concentration at Rock Slough, as shown in Figures 29 and 31, ranged between 2 and 8 mg/l. Further south at the State Water Project (see Figures 30 and 37), DOC ranged from 2.5 mg/l to 5.5 mg/l. The maximum monthly averaged DOC concentration at all four export locations over the entire 16-year planning study is summarized in Table 6.

Table 6: Maximum monthly averaged DOC (mg/l) concentrations.

Location	*Base*	*Low (6 mg/l)*	*Mid (15 mg/l)*	*High (30 mg/l)*
Old River at Rock Slough	8.10	7.03	7.03	7.03
Old River at Los Vaqueros intake	7.90	7.57	10.59	19.37
State Water Project	5.43	5.11	7.89	12.57
Central Valley Project	5.13	5.01	7.47	11.58

In the base case, the periods of high DOC for all of the locations coincided with the high runoff periods that start in the spring and sometimes last through early summer. The *DOC ag credit* discussed above typically appeared to lower the DOC concentrations in the early spring period for all three bookend scenarios at Rock Slough (see Figure 31), but was less significant at the other three urban intake locations (see Figures 34, 37, and 40). The increases in the maximum monthly averaged DOC concentration at all four intake locations in the alternative scenarios occurred in the summer months and correspond with the project island release periods.

The Los Vaqueros intake on the Old River had the highest modeled DOC concentrations for all three alternative scenarios. The Los Vaqueros intake is located between the Bacon Island discharge point and the SWP and CVP intakes, so it is not surprising that the DOC concentrations for Los Vaqueros are higher than the other three locations.

The maximum monthly increase in DOC for each of the bookend scenarios is shown in Table 7. The largest increases for all three simulations were at the Los Vaqueros intake.

Table 7: Maximum monthly increase in DOC (mg/l).

Location	*Low – Base*	*Mid - Base*	*High - Base*
Old River at Rock Slough	0.34	1.63	3.77
Old River at Los Vaqueros intake	0.95	5.97	14.75
State Water Project	0.66	3.09	12.57
Central Valley Project	0.66	3.00	6.91

The impact of the project operations is better illustrated in Figures 32, 36, 39, and 42 as a time series of the change in DOC (alternative – base). The WQMP limits the maximum increase in DOC due to project operations based on the modeled base case DOC concentration. When the base case DOC is either less than 3 mg/l or greater than 4 mg/l, the maximum increase in DOC is 1 mg/l. When the base case DOC is between 3 mg/l and 4 mg/l, then the alternative DOC can not exceed 4 mg/l. This standard is illustrated as a changing time series with values between 0 to 1 mg/l.

At Old River at Rock Slough the low – base difference did not exceed the WQMP maximum increase in DOC standard. With the exception of the summers of 1984 and 1987 the mid – base difference exceeded the WQMP maximum increase standard. Furthermore, it should be noted that the Webb Tract release in the summer of 1987 was only 432 cfs and there was no Bacon Island release during this period (see Figure 2), which explains why even the high – base difference did not exceed the maximum increase standard in 1987.[4] There was a similar trend in results at the other three urban intake locations. However, the low – base difference did exceed the WQMP at each of the other three urban intake locations in the summer of 1981 (see Figures 35, 38, and 41).

Frequency histograms of the change in DOC for the entire simulation period were used to create cumulative distribution functions (cdfs) representing the relative change in DOC for each location. These cdfs are shown in Figures 34, 37, 40, and 43. On each cdf, a 1 mg/l limit is shown. The point where this limit intersects each of the three cdf curves represents the percentage of time that the change in DOC due to project operations will be equal to or less than the limit

For example, according to Figure 34, high DOC releases from the project islands will result in changes in DOC at Rock Slough that are equal to or less than 1 mg/l 90% of the time. Similarly, this means that 10% of the time the operation of the project will result in increases in DOC at Rock Slough that are greater than 1 mg/l. A summary of the increases in DOC due to the operation of the project for the entire simulation period is shown below in Table 8.

Table 8: Percent of time that the change in DOC is larger than 1 mg/l.

Location	***% Exceedence Low – Base***	***% Exceedence Mid – Base***	***% Exceedence High – Base***
Old River at Rock Slough	0	4.7	9.9
Old River at Los Vaqueros intake	0	7.3	14.6
State Water Project	0	4.7	10.9
Central Valley Project	0	4.7	10.9

[4] The Delta Wetlands preliminary operational diversion and release schedule did not completely fill Bacon Island in the spring of 1987. Using the operational rules discussed in Section 2.2, the summer releases of 1987 were met using the over-year storage of Webb Tract. The summer 1987 release was only 432 cfs, which is less than half of any of the other releases from Webb Tract. According to the Delta Wetlands operational release schedule Webb Tract releases typically ranged from 1000 to 1500 cfs.

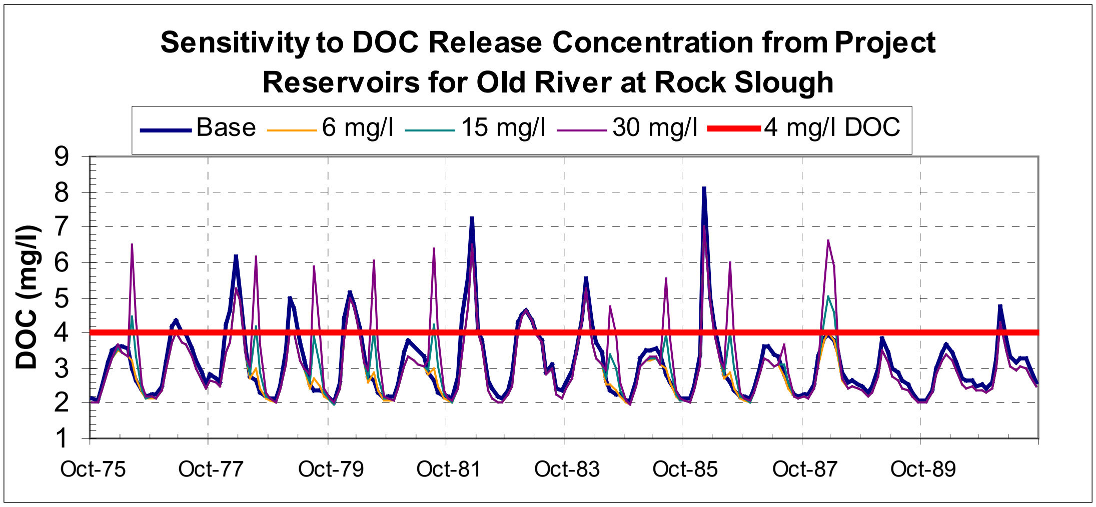


Figure 31: Time Series of DOC for Old River at Rock Slough.

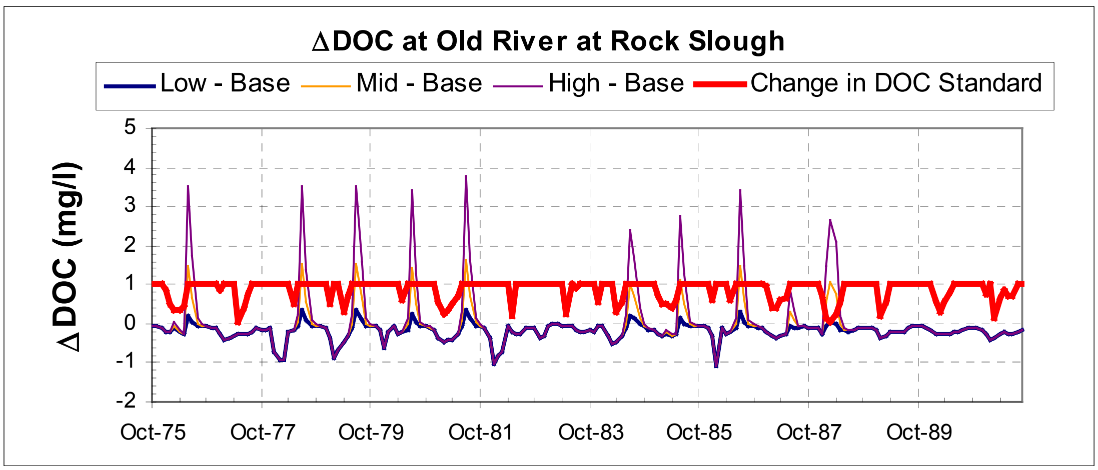


Figure 32: Time Series of Change in DOC (Alternative – Base) for Old River at Rock Slough.

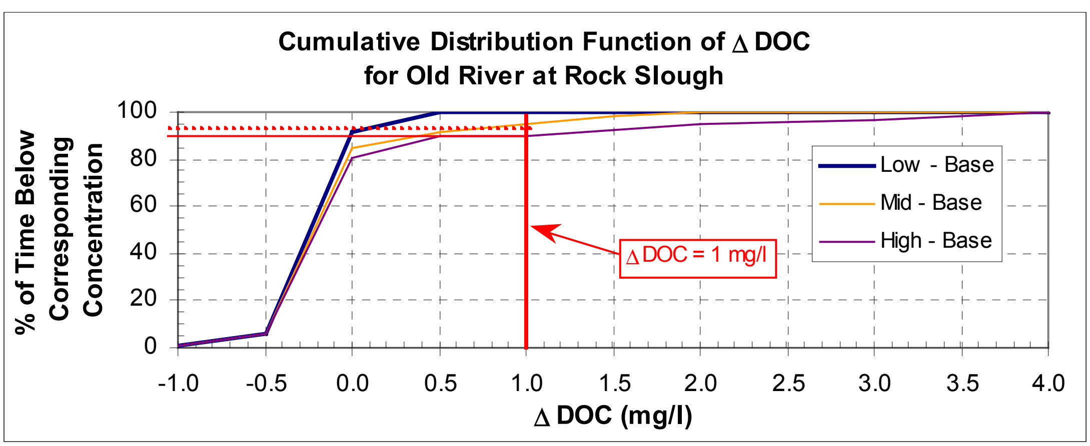


Figure 33: Cumulative Distribution Function of Change in DOC (Alternative – Base) for Old River at Rock Slough.

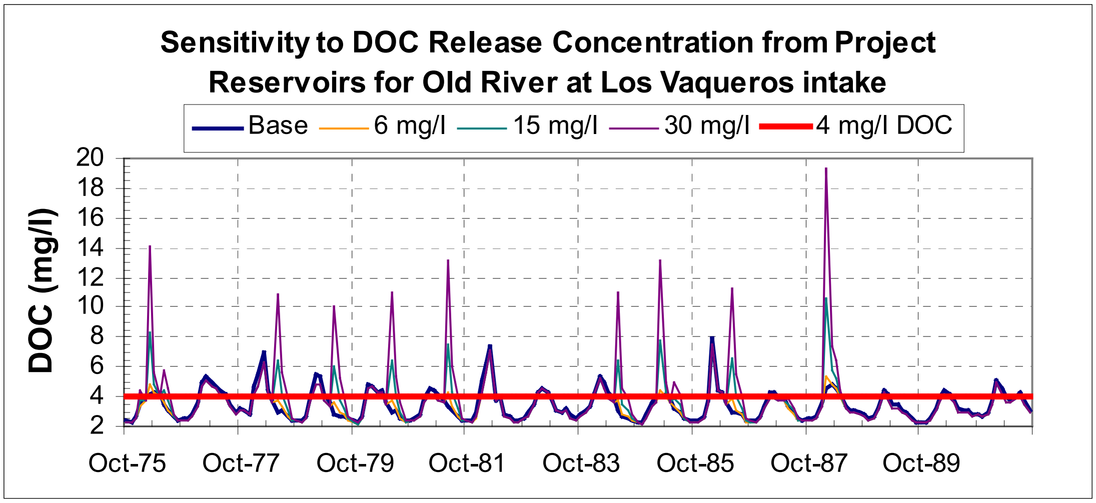


Figure 34: Time Series of DOC for Old River at Los Vaqueros intake.

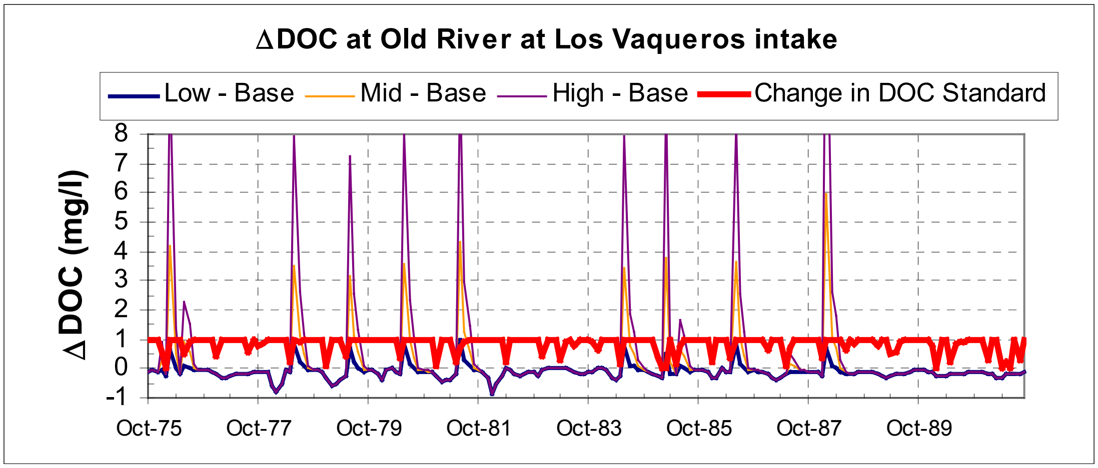


Figure 35: Time Series of Change in DOC (Alternative – Base) for Old River at Los Vaqueros intake.

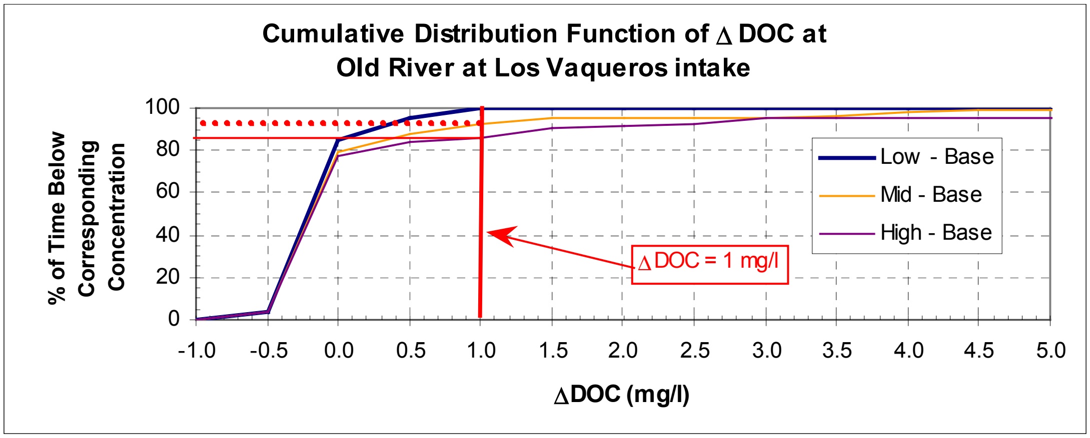


Figure 36: Cumulative Distribution Function of Change in DOC (Alternative – Base) for Old River at Los Vaqueros intake.

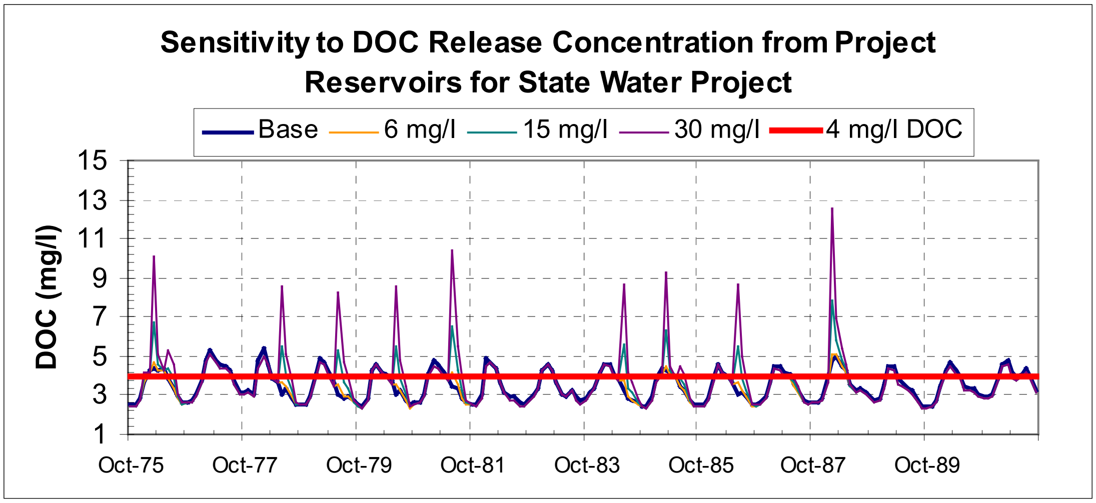


Figure 37: Time Series of DOC for the State Water Project.

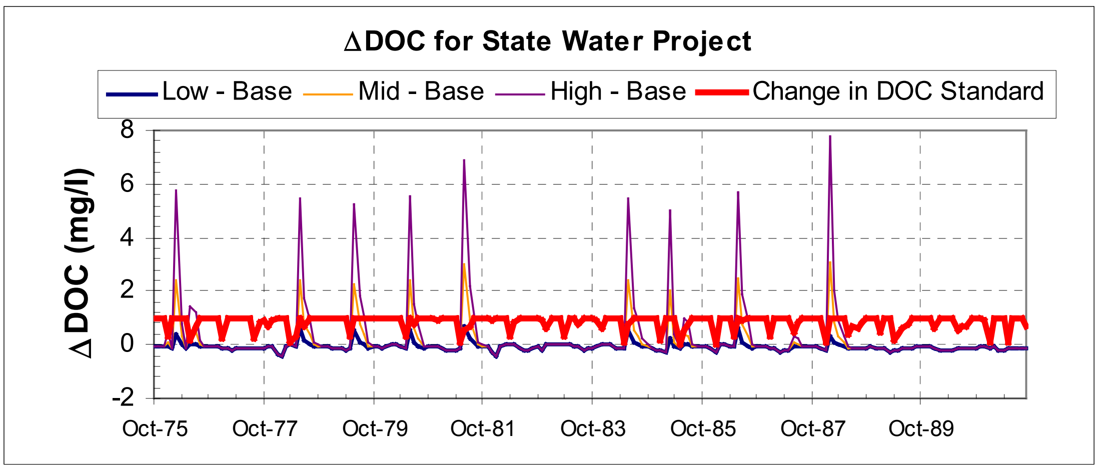


Figure 38: Time Series of Change in DOC (Alternative – Base) for the State Water Project.

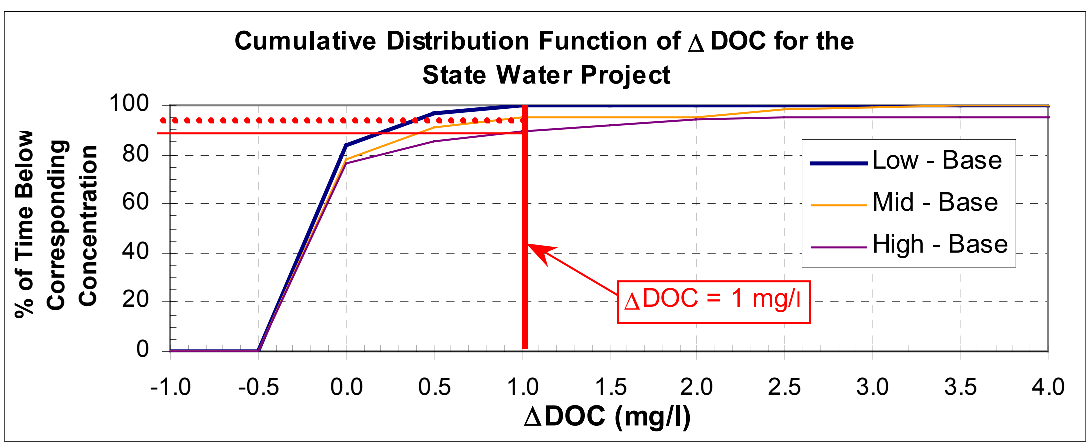


Figure 39: Cumulative Distribution Function of Change in DOC (Alternative – Base) for the State Water Project.

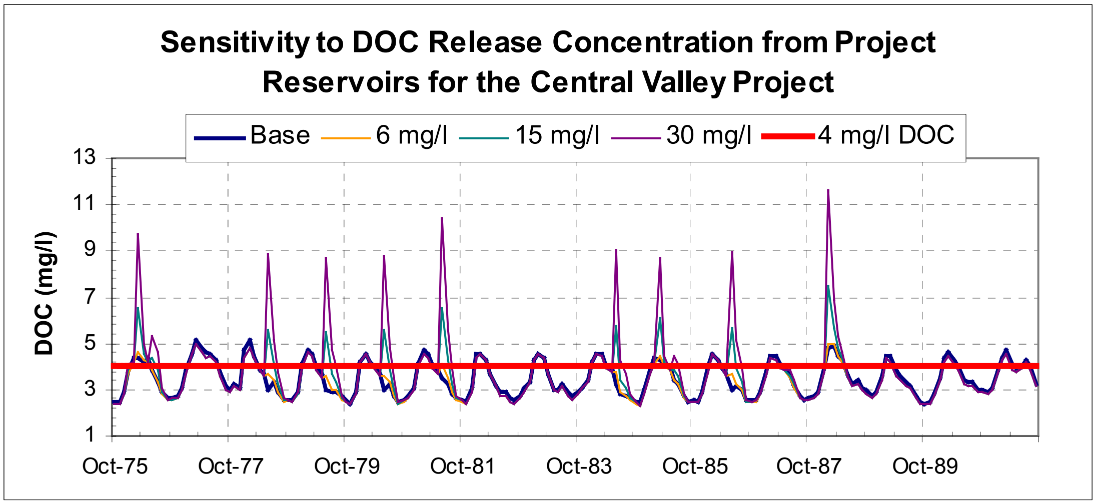


Figure 40: Time Series of DOC for the Central Valley Project.

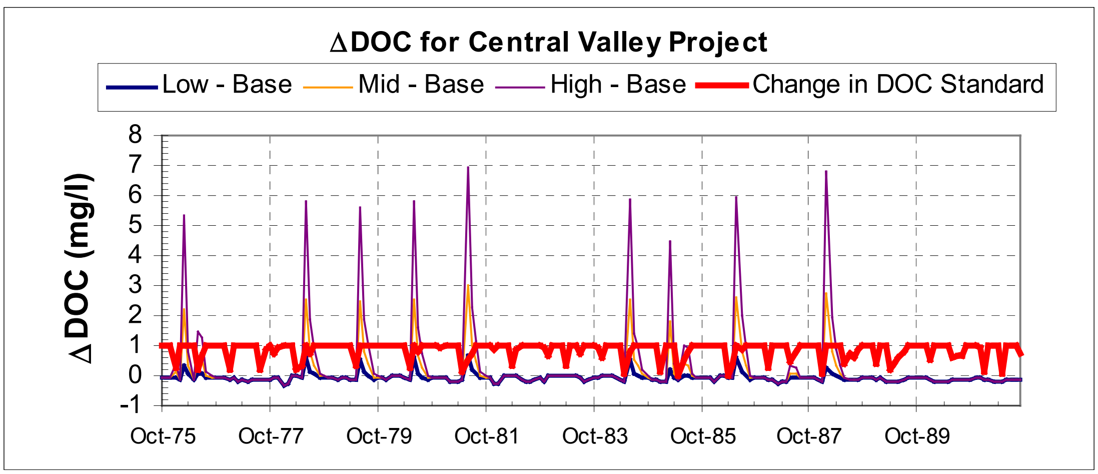


Figure 41: Time Series of Change in DOC (Alternative – Base) for the Central Valley Project.

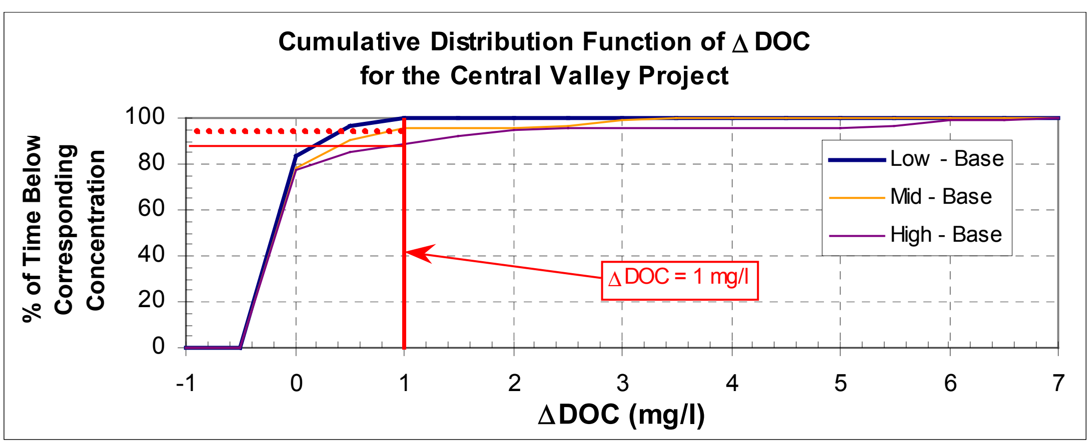


Figure 42: Cumulative Distribution Function of Change in DOC (Alternative – Base) for the Central Valley Project.

4.3. Long-Term DOC

The mass loading of DOC for the State Water Project and Central Valley Project was calculated by multiplying the DSM2 modeled DOC concentrations with the DWRSIM 771 monthly exports for each location. The mass loading of DOC for the Old River at Rock Slough and Old River at the Los Vaqueros Intake was calculated by multiplying the DSM2 modeled DOC concentrations with planned future CCWD diversions developed using CCWD's CCWDOPs model (Denton 2001)[5].

The WQMP stipulated that the long-term increase in DOC mass loading be calculated as a 3-year running average. Time series plots of the long-term DOC mass loading (expressed in 1000 metric tons / month) at each of the urban intake locations are shown in Figures 43, 46, 49, and 52. The low-DOC release concentration (6 mg/l) from the project islands resulted in long-term DOC mass loading that closely resembled the base case long-term DOC mass loading at all four urban intake locations. Similarly, the high-DOC release concentration (30 mg/l) from the project islands was uniformly higher than the base case DOC mass loading.

The 3-year running averages for both the base case and alternative scenarios were then used to calculate the increases in long-term DOC mass loading using Equation 4.

$$\%DOC_{Increase\, w/\, Project} = \frac{DOC_{w/\, Project} - DOC_{w/o\, project}}{DOC_{w/o\, project}} \times 100\% \qquad \text{[Eqn. 4]}$$

The WQMP limits the long-term DOC mass loading increases at the intake locations due to the project operation to 5%. This 5% limit is shown on the time series plots (Figures 44, 47, 50, and 53) of the long-term percent increase of DOC mass loading at each of the intake locations. As discussed above, the low-DOC release concentration from the project islands did not result in a long-term increase in DOC mass loading at any of the intakes. The maximum percent increases in the long-term DOC mass loading are shown in Table 9.

Table 9: Maximum Percent Increase in Long-Term DOC Mass Loading.

Location	*Low – Base*	*Mid – Base*	*High – Base*
Old River at Rock Slough	-2	12	33
Old River at Los Vaqueros intake	0	14	38
State Water Project	-1	6	18
Central Valley Project	0	9	23

Frequency histograms of the percent increase in long-term DOC mass loading for the entire simulation period were used to create cumulative distribution functions (cdfs) to represent the long-term impact of the project operations. These cdfs are shown in Figures

[5] The DSM2 simulation did not separate the CCWD diversions from Old River at Rock Slough and Old River at the Los Vaqueros Intake location. Instead DWRSIM 771 diversions at Rock Slough were used to represent CCWD's total diversions. Future DSM2 simulations will make use of the CCWD CCWDOPs planned diversion data.

45, 48, 51, and 54. The WQMP maximum 5% increase in long-term DOC mass loading standard is shown on each figure. The low-DOC release scenario did not exceed this WQMP standard for any of the intake locations. However, both the mid- and high-DOC release scenarios exceeded the 5% limit at each location.

The percent of the time that each scenario was equal to or below the WQMP maximum 5% increase standard is shown in Table 10. The largest increases in long-term DOC mass loading occurred at Los Vaqueros Reservoir intake on the Old River.

Table 10: Percent Time that the Percent Increase of Long-Term DOC Mass Loading meets the WQMP maximum 5% increase standard.

Location	***Low – Base***	***Mid – Base***	***High – Base***
Old River at Rock Slough	100	48	29
Old River at Los Vaqueros intake	100	39	4
State Water Project	100	84	30
Central Valley Project	100	66	21

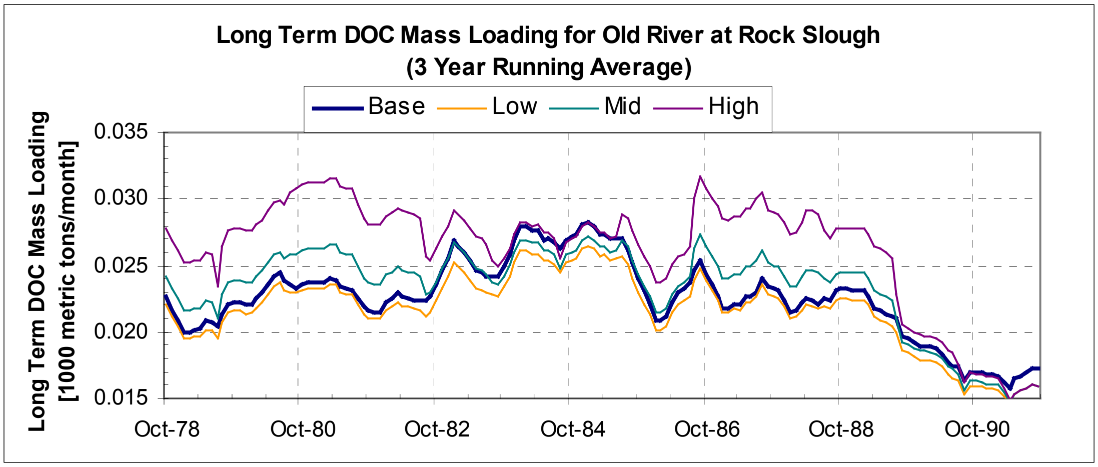


Figure 43: Long Term DOC Mass Loading for Old River at Rock Slough based on a 3-Year Running Average.

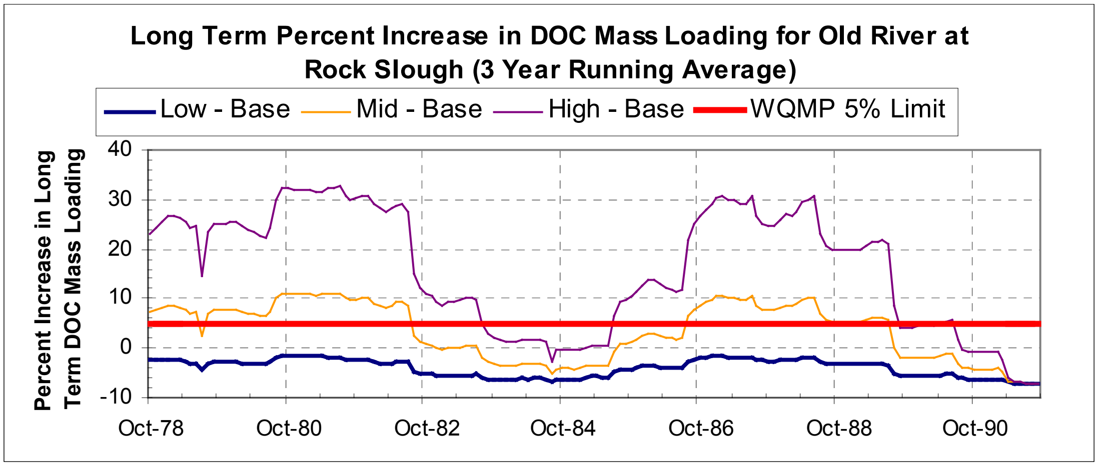


Figure 44: Percent Increase in Long Term DOC Mass Loading for Old River at Rock Slough based on a 3-Year Running Average.

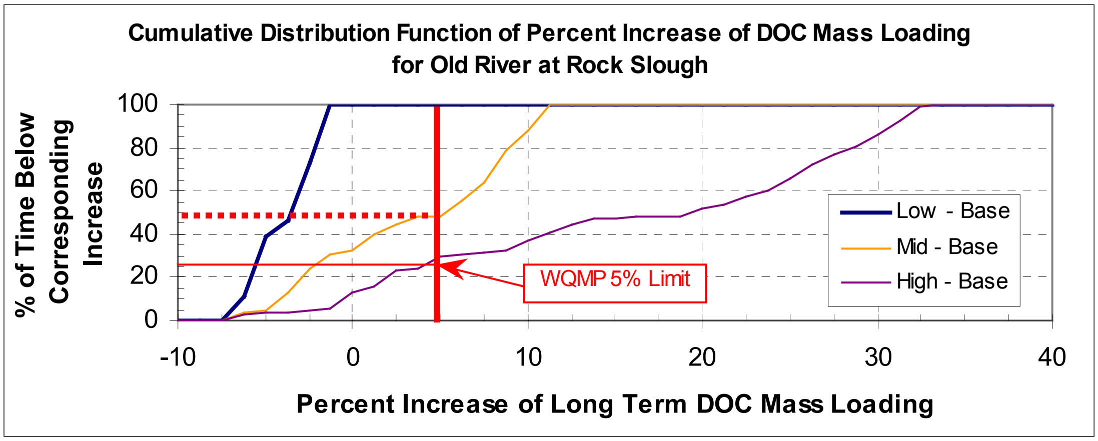


Figure 45: Cumulative Distribution Function of Percent Increase of Long Term DOC Mass Loading for Old River at Rock Slough.

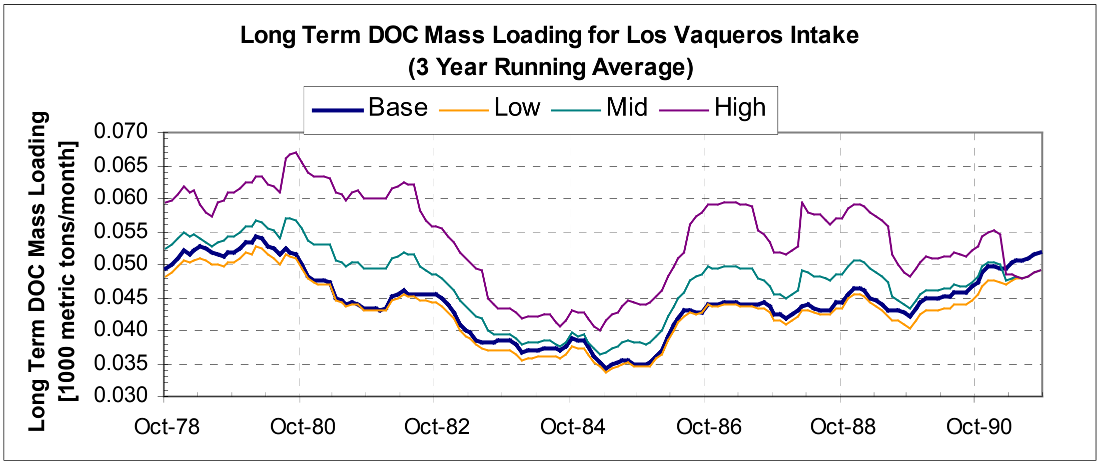


Figure 46: Long Term DOC Mass Loading for Old River at Los Vaqueros intake based on a 3-Year Running Average.

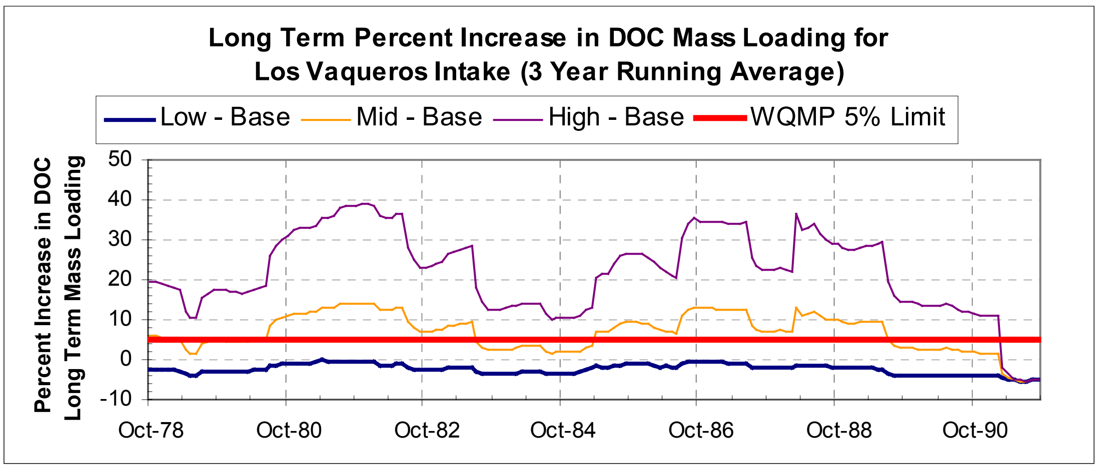


Figure 47: Percent Increase in Long Term DOC Mass Loading for Old River at Los Vaqueros intake based on a 3-Year Running Average.

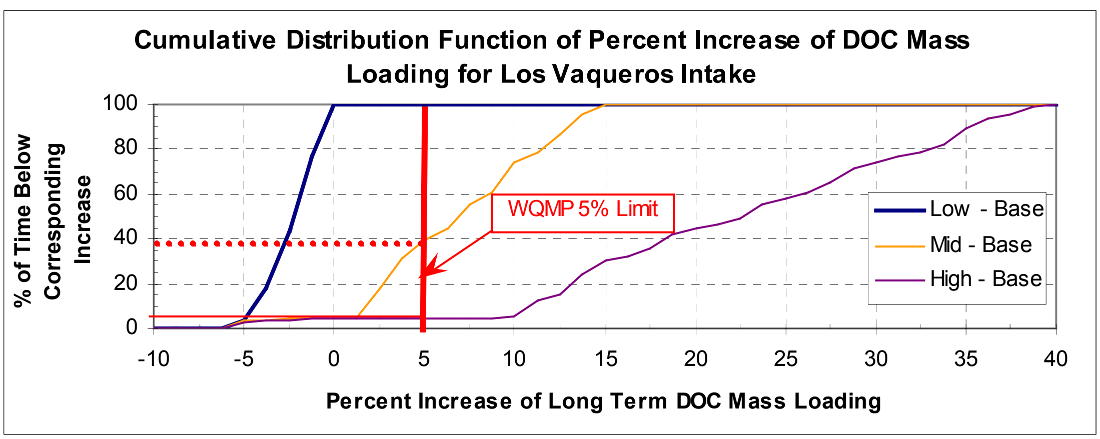


Figure 48: Cumulative Distribution Function of Percent Increase of Long Term DOC Mass Loading for Old River at Los Vaqueros intake.

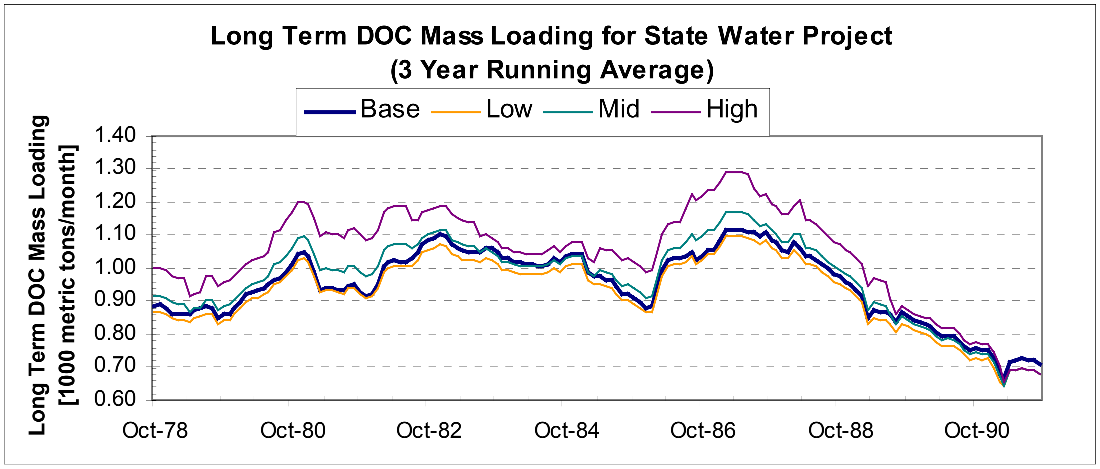


Figure 49: Long Term DOC Mass Loading for State Water Project based on a 3-Year Running Average.

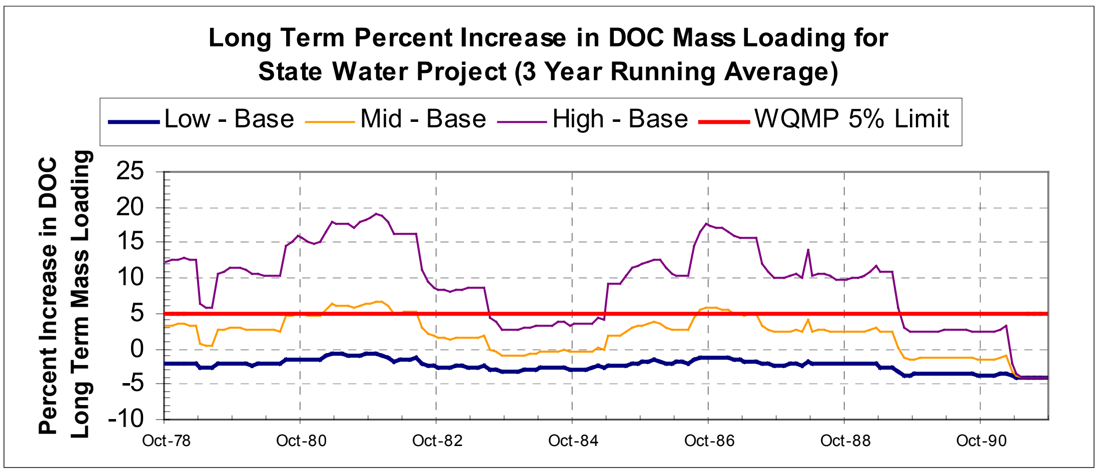


Figure 50: Percent Increase in Long Term DOC Mass Loading for State Water Project based on a 3-Year Running Average.

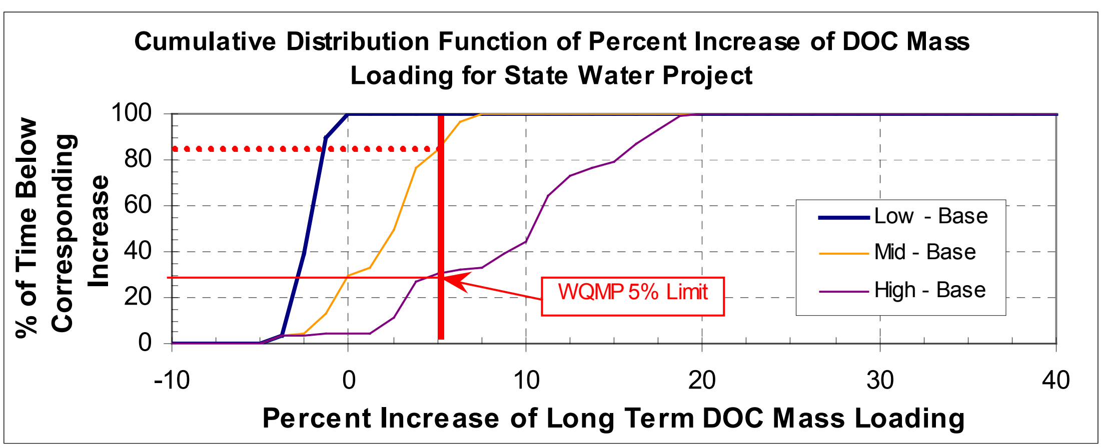


Figure 51: Cumulative Distribution Function of Percent Increase of Long Term DOC Mass Loading for State Water Project.

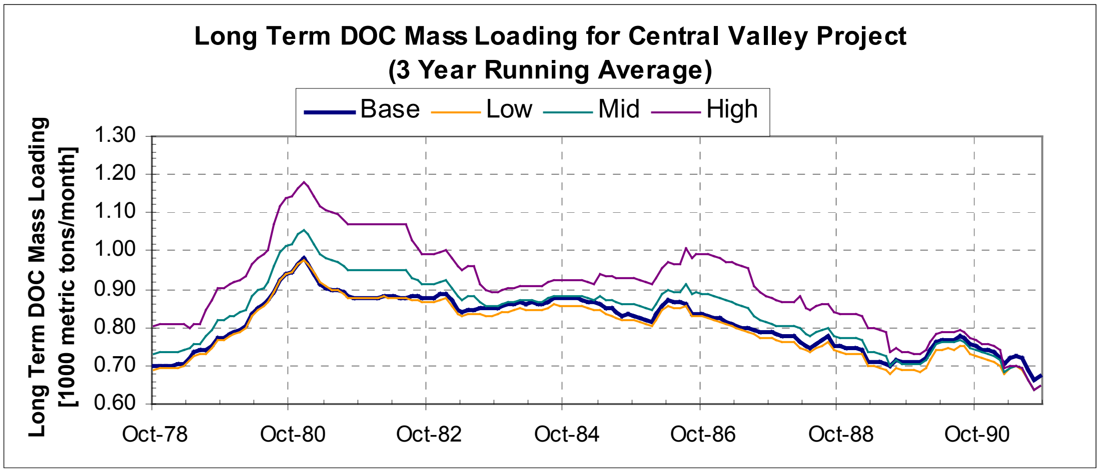


Figure 52: Long Term DOC Mass Loading for Central Valley Project based on a 3-Year Running Average.

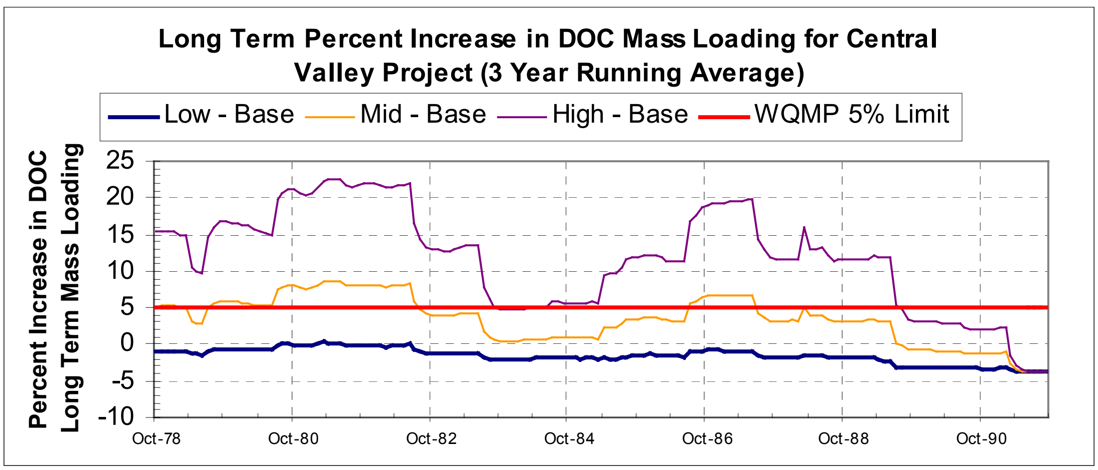


Figure 53: Percent Increase in Long Term DOC Mass Loading for Central Valley Project based on a 3-Year Running Average.

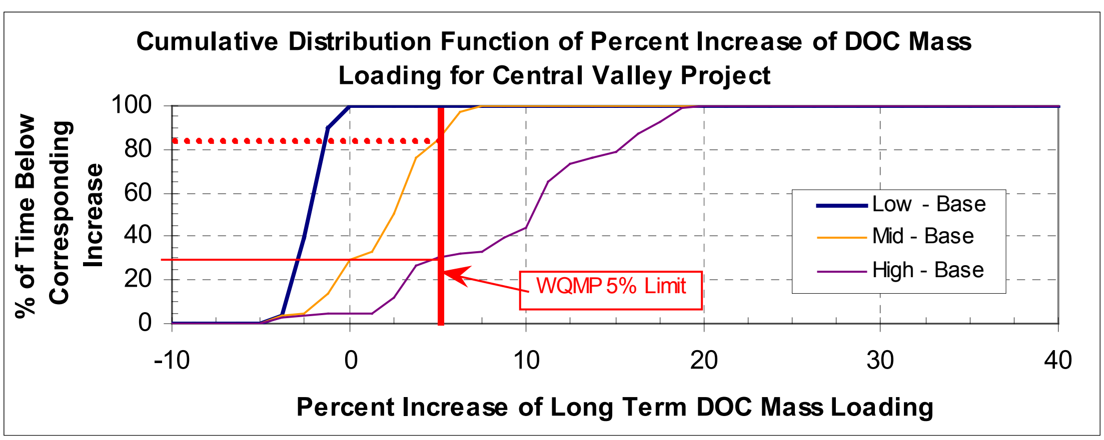


Figure 54: Cumulative Distribution Function of Percent Increase of Long Term DOC Mass Loading for Central Valley Project.

4.4. UVA

Three different UVA simulations were run to find UVA levels at the four urban water intakes due to the operation of the Delta Wetlands project that could later be used to compute TTHM (see Section 4.5). The level of the UVA releases for each of these bookend simulations is described above in Table 4 (see Section 2.2).

The UVA simulations were treated similar to the DOC simulations (see Section 4.2). The diversions into the reservoirs were treated as standard diversions. Water was removed from the Delta at the planned intake locations. Similarly, the releases from the islands were treated as rim or return flows at the planned discharge locations. Fixed UVA measurements were assigned to these releases. The UVA from these project island releases mixed with the already present in channel UVA.

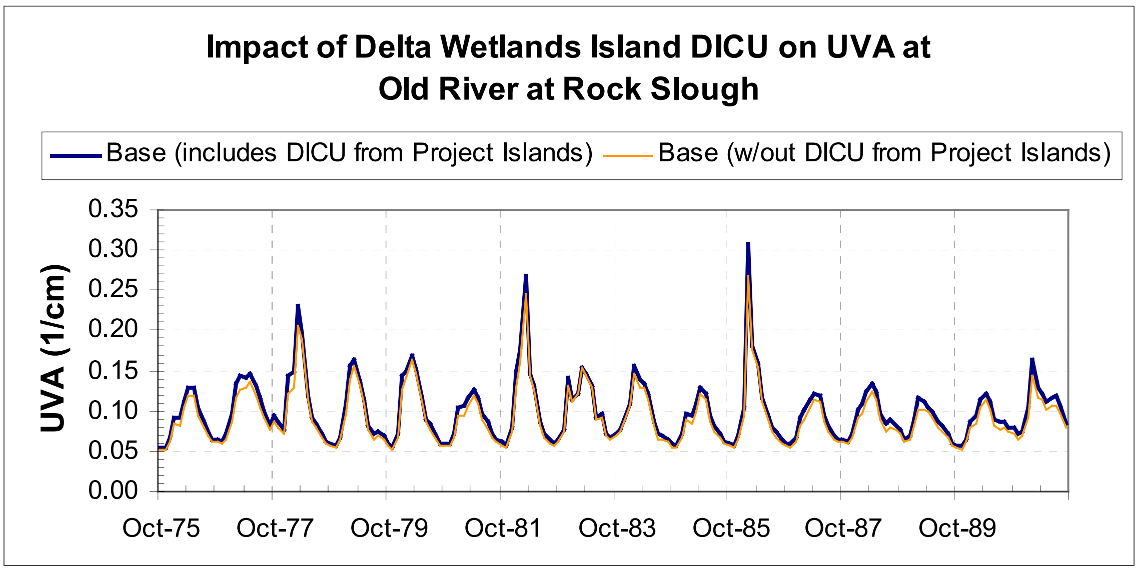


Figure 55: Effect of DICU around the Delta Wetlands Islands on Old River at Rock Slough.

As with the *DOC ag credit* (see Section 4.2) the benefit of changing the agricultural diversions and returns on the project islands at Rock Slough is shown above in Figure 55. This benefit, referred to as the *UVA ag credit*, was found to be relatively small at all four of the intake locations.

Figures 56, 58, 60, and 62 illustrate the sensitivity to UVA release measurements at each of the four urban intake locations: Old River at Rock Slough, Old River at the Los Vaqueros intake, the State Water Project intake at Banks Pumping Plant, and the Central Valley Project intake at Tracy. In the base case, the periods of high UVA for all of the locations coincided with the high runoff periods that start in the spring and sometimes continue through early summer. The summer releases from the project islands resulted in UVA measurement increases for all three bookend levels. At Rock Slough (see Figure 56), the process of releasing water during the summer at the mid and high bookend UVA values, effectively increased the number of times over the 16-year period that the UVA measurement at Rock Slough reached above 0.20 cm^{-1}. However, these higher measurements did not exceed the winter monthly maximum from the base case. At the other three intake locations, the summer project water did exceed the base case monthly maximum. Furthermore Los Vaqueros, the State Water Project, and the Central Valley Project were much more sensitive to UVA releases from the project islands. Rock Slough is located to the north of the Bacon Island discharge location, and given that the predominant flows on the Old River tend to be heading south, Bacon Island releases have less of an impact on Rock Slough.

The maximum monthly averaged UVA at these four locations over the entire 16-year planning study is summarized in Table 11. As shown in Figure 10, the monthly agricultural UVA measurements from all of the Delta islands range from around 0.25 to 1.60 cm^{-1}. For all three bookend simulations, the largest maximum monthly UVA measurements were observed at Los Vaqueros. The maximum monthly change in UVA measurement is shown in Table 12. Again the largest changes were observed at Los Vaqueros, which is closer to the project islands than the SWP and CVP intakes.

Table 11: Maximum monthly averaged UVA (cm^{-1}) measurements.

Location	*Base*	*Low (0.289 cm^{-1})*	*Mid (0.686 cm^{-1})*	*High (1.348 cm^{-1})*
Old River at Rock Slough	0.309	0.263	0.263	0.267
Old River at Los Vaqueros intake	0.308	0.296	0.461	0.848
State Water Project	0.189	0.187	0.311	0.517
Central Valley Project	0.182	0.182	0.286	0.467

Table 12: Maximum monthly change in UVA (cm^{-1}).

Location	*Low – Base*	*Mid - Base*	*High - Base*
Old River at Rock Slough	0.022	0.079	0.174
Old River at Los Vaqueros intake	0.078	0.310	0.698
State Water Project	0.043	0.162	0.368
Central Valley Project	0.043	0.146	0.323

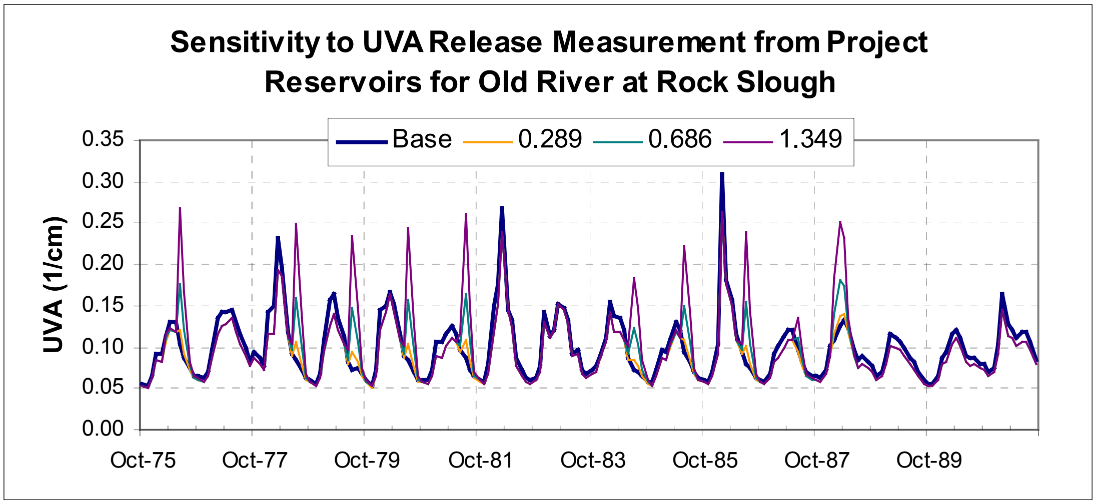


Figure 56: Time Series of UVA for Old River at Rock Slough.

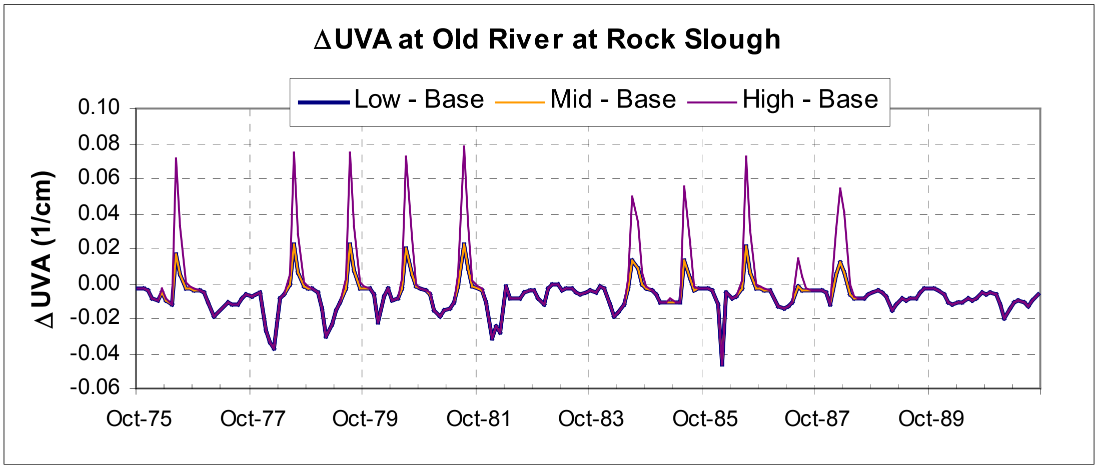


Figure 57: Time Series of Change in UVA (Alternative – Base) for Old River at Rock Slough.

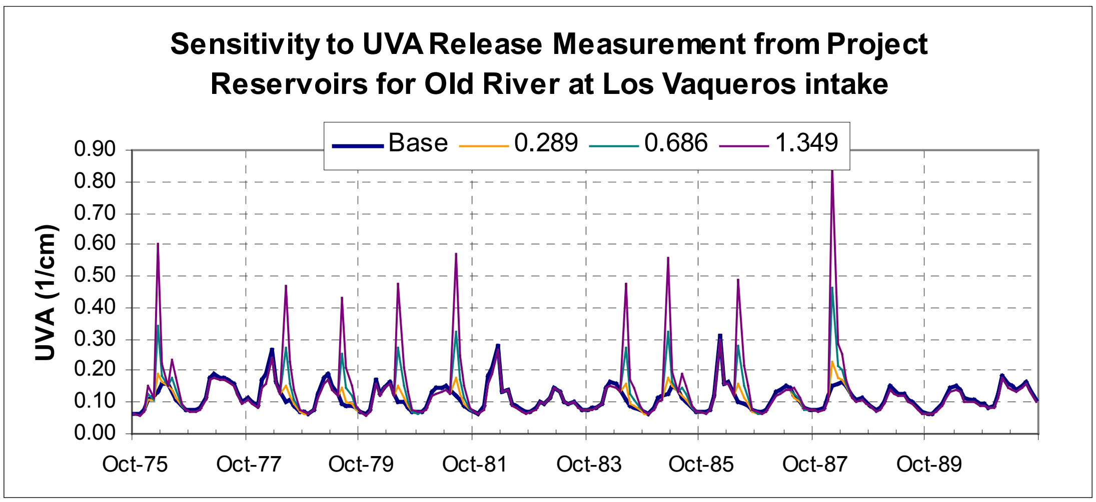


Figure 58: Time Series of UVA for Old River at Los Vaqueros intake.

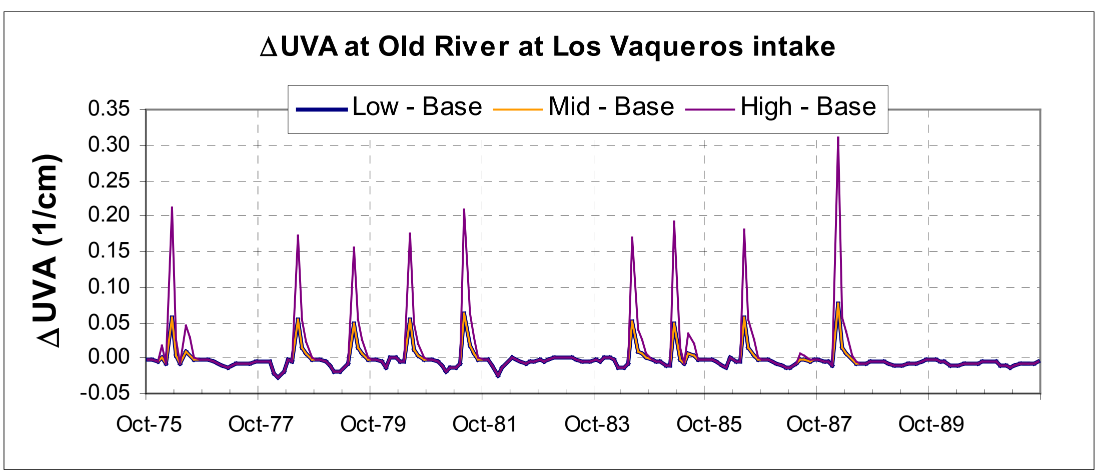


Figure 59: Time Series of Change in UVA (Alternative – Base) for Old River at Los Vaqueros intake.

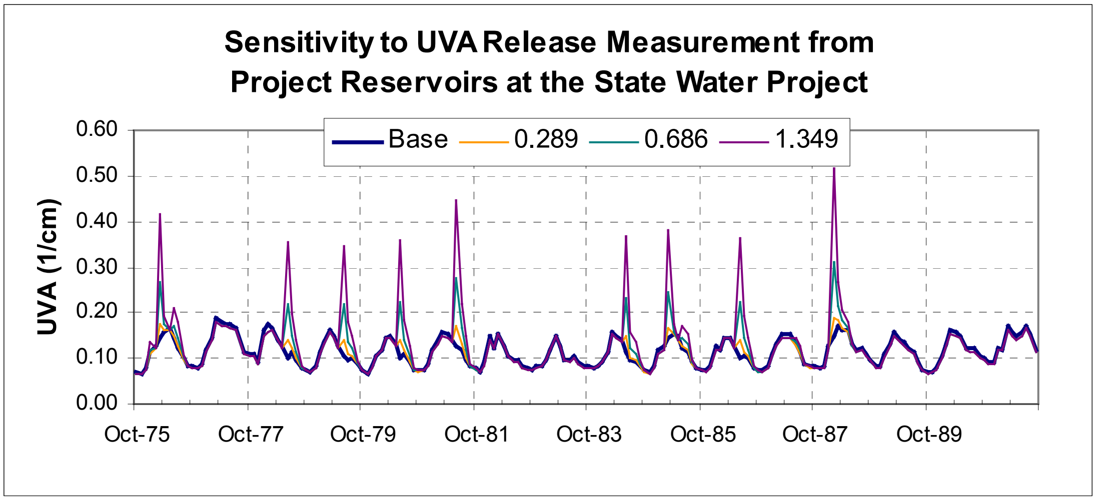


Figure 60: Time Series of UVA for the State Water Project.

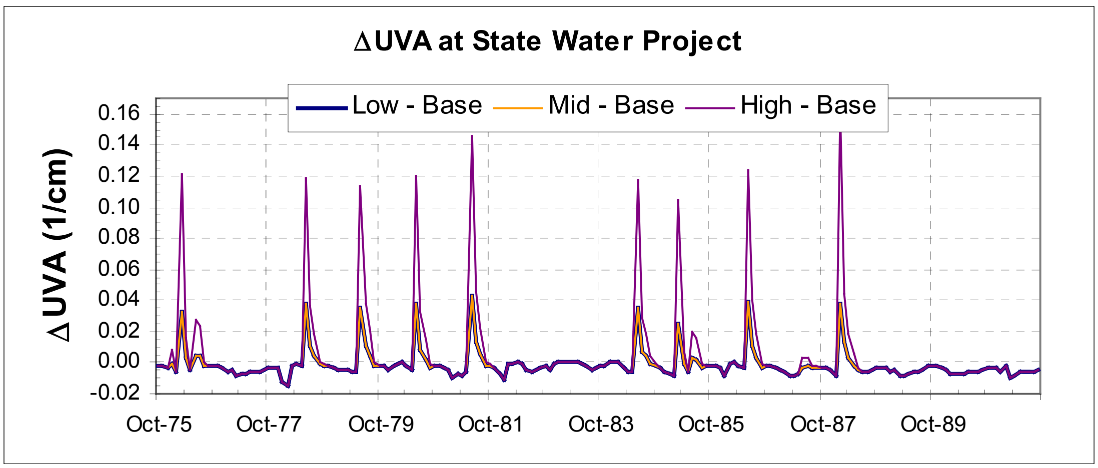


Figure 61: Time Series of Change in UVA (Alternative – Base) for the State Water Project.

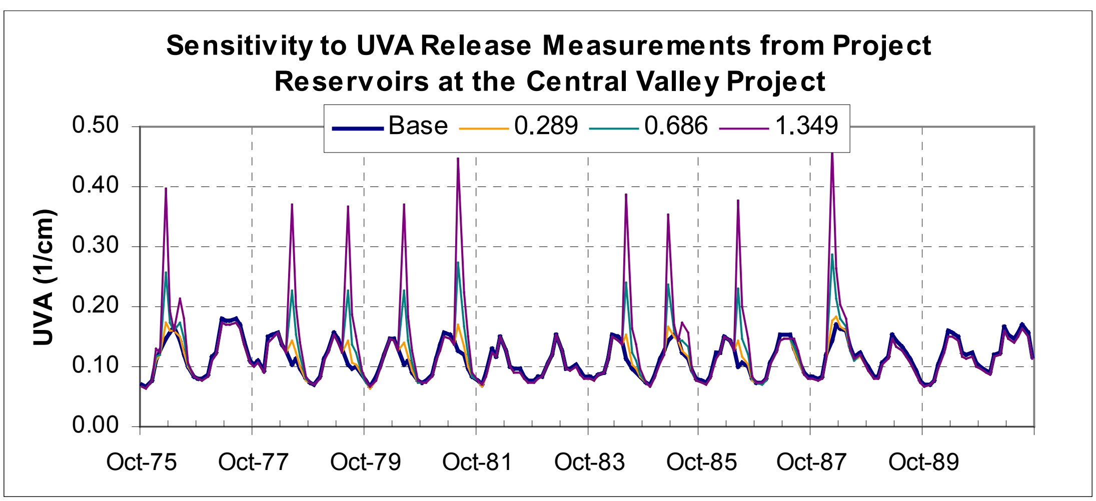


Figure 62: Time Series of UVA for the Central Valley Project.

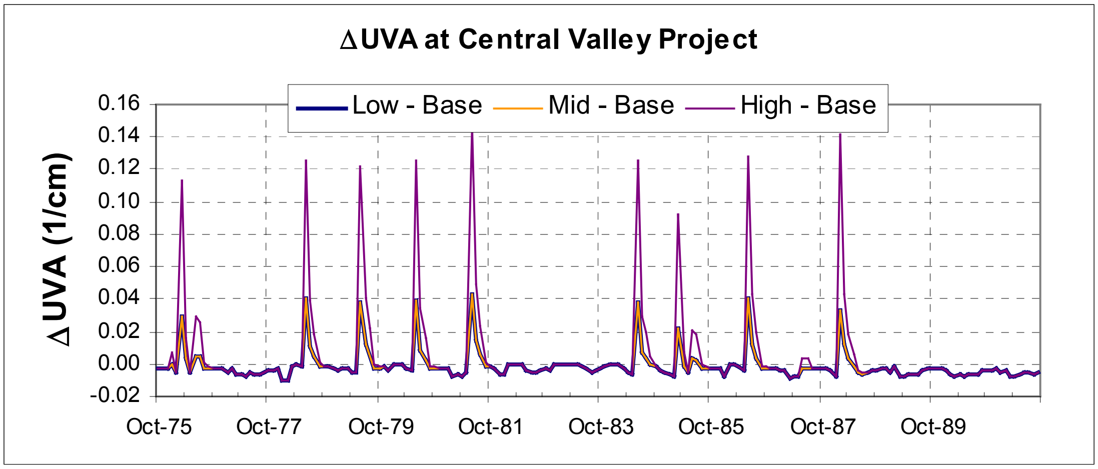


Figure 63: Time Series of Change in UVA (Alternative – Base) for the Central Valley Project.

4.5. TTHM

According to the WQMP Total Trihalomethane (TTHM) formation is limited 64 ug/l. For periods when the modeled base case exceeds this 64 ug/l standard, the WQMP permitted a 5% increase above the standard (3.2 ug/l) due to operation of the Delta Wetlands project.

Using the EC, DOC, and UVA results from each of the DSM2 bookend simulations, the TTHM for Old River at Rock Slough was calculated as:

$$TTHM = C_1 \times DOC^{0.228} \times UVA^{0.534} \times (Br+1)^{2.01} \times T^{0.48} \qquad \text{[Eqn. 5]}$$

where

TTHM = total trihalomethane concentration (ug/l),
C_1 = 14.5 when DOC < 4 mg/l,
C_1 = 12.5 when DOC ≥ 4 mg/l,
DOC = raw water dissolved organic carbon (mg/l) from DSM2,
UVA = raw water ultraviolet absorbance at 254 nm (1/cm) from DSM2,
Br = raw water bromide concentration (mg/l) as converted from DSM2, and
T = raw water temperature.

The bromide concentration at Rock Slough was developed by Bob Suits (2001) from regressions of observed (1) Contra Costa Canal Pumping Plant #1 Chloride data to Contra Costa Canal Pumping Plant #1 Bromide data, and (2) Contra Costa Canal Pumping Plant #1 Chloride data to Rock Slough EC. The bromide relationship used in Equation 5 for Rock Slough is:

$$Br_{Rock\,Slough} = \frac{EC_{Rock\,Slough} - 118.7}{1040.3} \qquad \text{[Eqn. 6]}$$

The bromide relationship for the remaining urban intake locations used in Equation 5 is:

$$Br = \frac{EC - 189.2}{1020.77} \qquad \text{[Eqn. 7]}$$

The monthly average water temperatures used in Equation 5 are shown below in Figure 64. These temperature data came from Contra Costa water treatment plant averages, as provided by K.T. Shum of Contra Costa Water District (Forkel, 2000b).

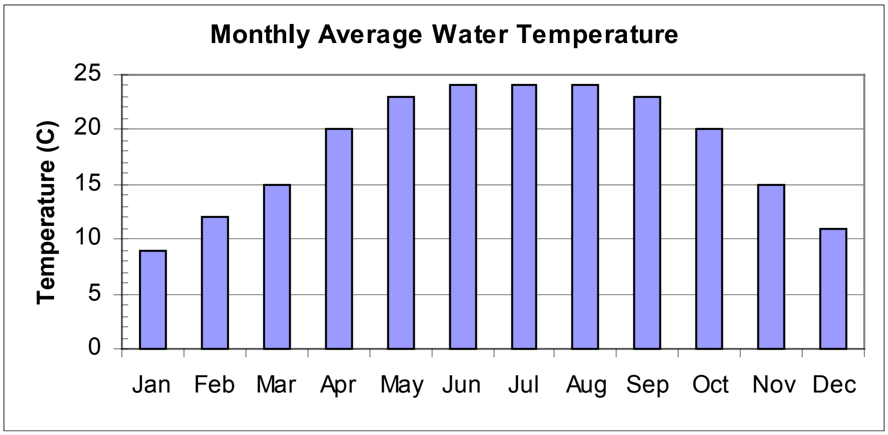


Figure 64: Monthly Average Water Temperature.

Using Equations 5, 6, and 7, the TTHM for all the urban intakes was calculated for the entire 16-year simulation period. The sensitivity to DOC release from the project islands is shown in Figures 65 – 72. The 64 ug/l WQMP standard is exceeded in the late fall and early winter months both in the base and alternative scenarios as is shown in Figures 65, 67, 69, and 71. This is consistent with the EC results discussed in Section 4.1, since bromide (which is directly related to EC) is a principal contributor to TTHM formation.

Table 13: Maximum monthly averaged TTHM (ug/l) concentrations.

Location	*Base*	*Low*	*Mid*	*High*
Old River at Rock Slough	131	124	124	124
Old River at Los Vaqueros	123	119	119	131
State Water Project	100	96	96	110
Central Valley Project	93	90	90	107

The maximum monthly TTHM concentrations for each of the simulations are displayed in Table 13. Since the EC and water temperature used to calculate the level of TTHM formation for each of the three bookend scenarios was the same, the differences in the TTHM concentrations is a function of the DOC and UVA values. For the Contra Costa intake at Old River at Rock Slough, the operation of the Delta Wetlands Project actually appears to decrease the maximum monthly TTHM concentrations. There was no significant difference between the three scenarios, but this is due to the fact that the DOC and UVA values at Rock Slough were very similar. For the other three intake locations, the high DOC and UVA release scenario results in increases in the maximum monthly

TTHM concentrations, while the other two scenarios result in slight decreases. It is important to remember that the majority of the releases from the project islands occur in the summer, and thus Table 13 does not provide a good estimate of the year round impact of the operation of the Delta Wetlands Project.

Time series plots (see Figures 66, 68, 70, and 72) illustrating the change between each alternative scenario and the base case provide a more useful tool to assess the impact of the project operation on TTHM formation. Although these plots show the change due to project operation over the entire simulation period, the intermittent 3.2 ug/l maximum increase in TTHM standard applies only at the times when the regular 64 ug/l standard was exceeded by the base case as shown in Figures 65, 67, 69, and 71. Even though releases from the project islands resulted in significant increases in TTHM at all four urban intake locations, typically these increases did not exceed the 64 ug/l standard, and thus according to the WQMP should not be constrained by the 3.2 ug/l maximum increase standard.

The largest increase in TTHM occurred in the summer of 1988 at the Los Vaqueros Reservoir intake location for both the mid and high levels of DOC release (see Figure 68). However, both of these increases exceeded 64 ug/l at a time when the base case was below the standard (see Figure 67). The maximum monthly increase in TTHM at the urban intake locations for only those times when the base case scenario exceeded the 64 ug/l standard is listed below in Table 14. Based on Table 14, there appears to be little difference between the scenarios. The only location where TTHM increased due to project operation was at Old River at Rock Slough.

Table 14: Maximum monthly increase in TTHM (ug/l) when base scenario was greater than the WQMP 64 ug/l standard.

Location	***Low – Base***	***Mid - Base***	***High - Base***
Old River at Rock Slough	4.39	4.40	4.40
Old River at Los Vaqueros intake	-1.42	-1.42	-1.29
State Water Project	-0.63	-0.63	-0.63
Central Valley Project	-0.58	-0.58	-0.58

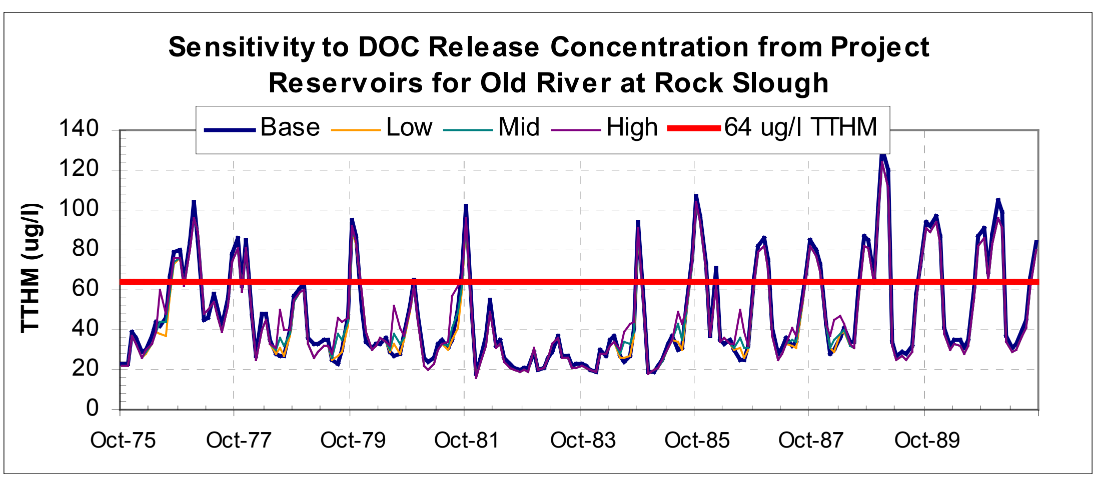


Figure 65: Time Series of TTHM Formation for Old River at Rock Slough.

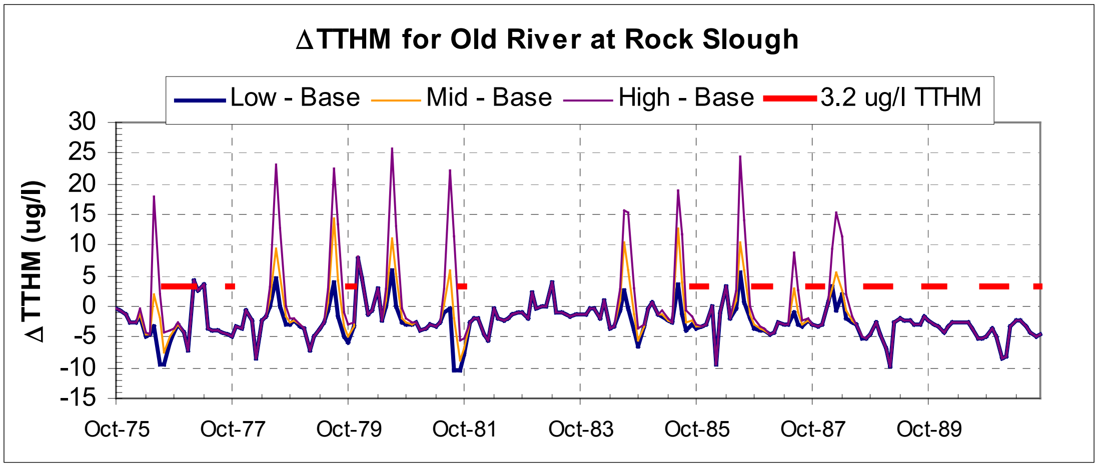


Figure 66: Time Series of Change in TTHM (Alternative – Base) for Old River at Rock Slough.

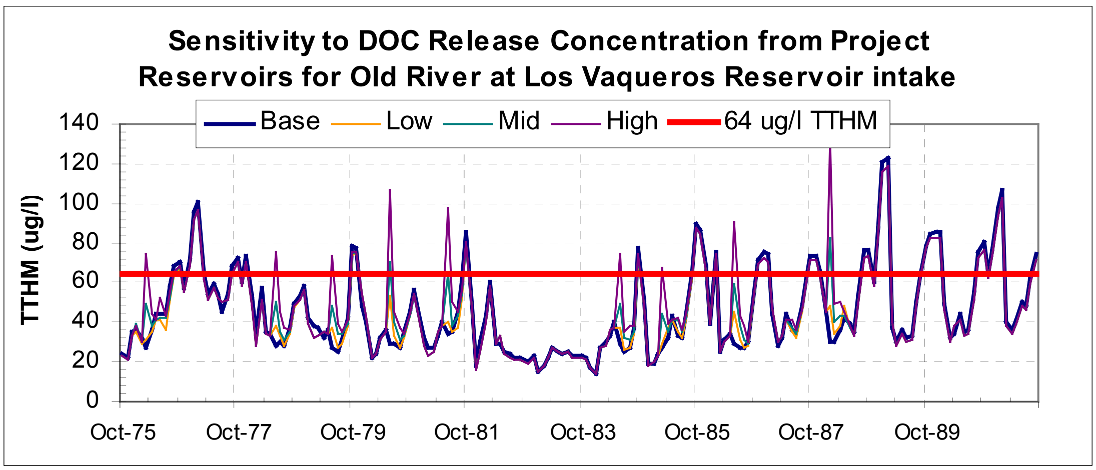


Figure 67: Time Series of TTHM Formation for Old River at Los Vaqueros intake.

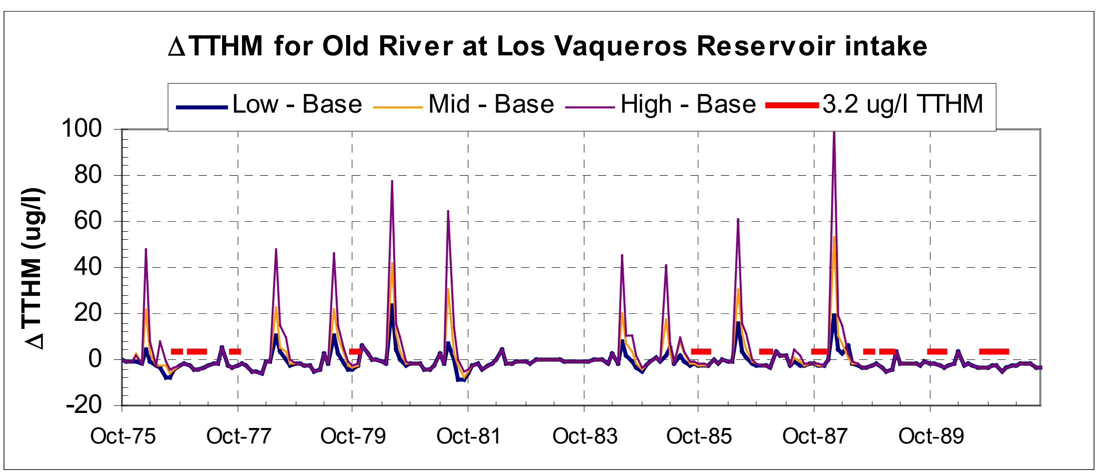


Figure 68: Time Series of Change in TTHM (Alternative – Base) for Old River at Los Vaqueros intake.

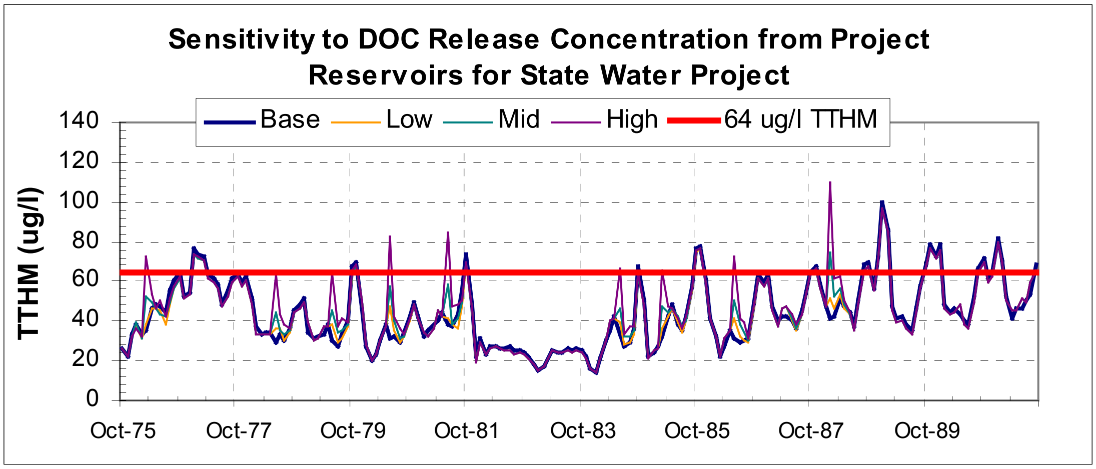


Figure 69: Time Series of TTHM Formation for State Water Project.

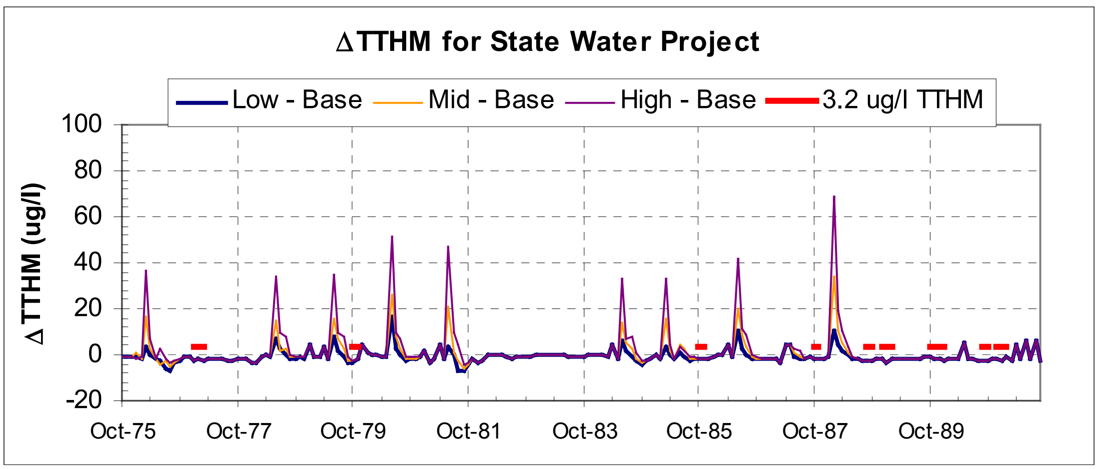


Figure 70: Time Series of Change in TTHM (Alternative – Base) for State Water Project.

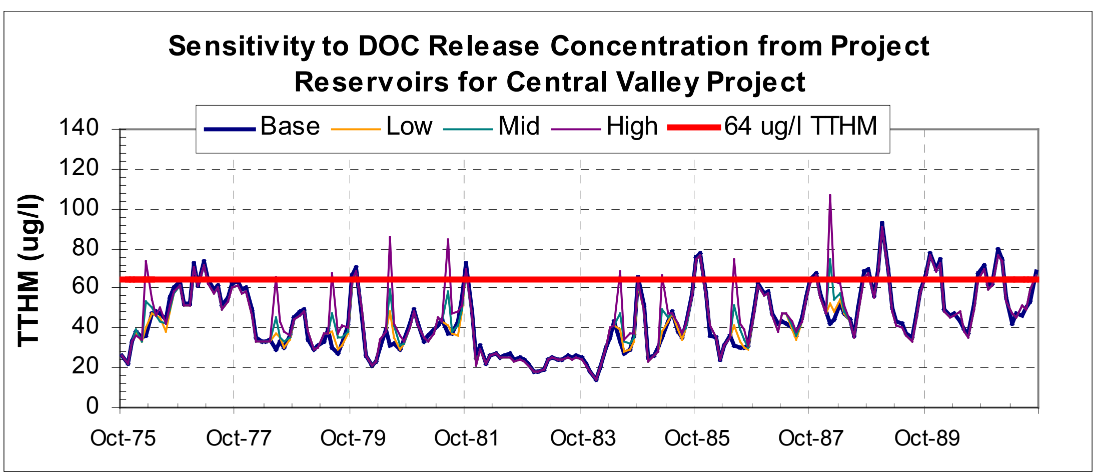


Figure 71: Time Series of TTHM Formation for State Water Project.

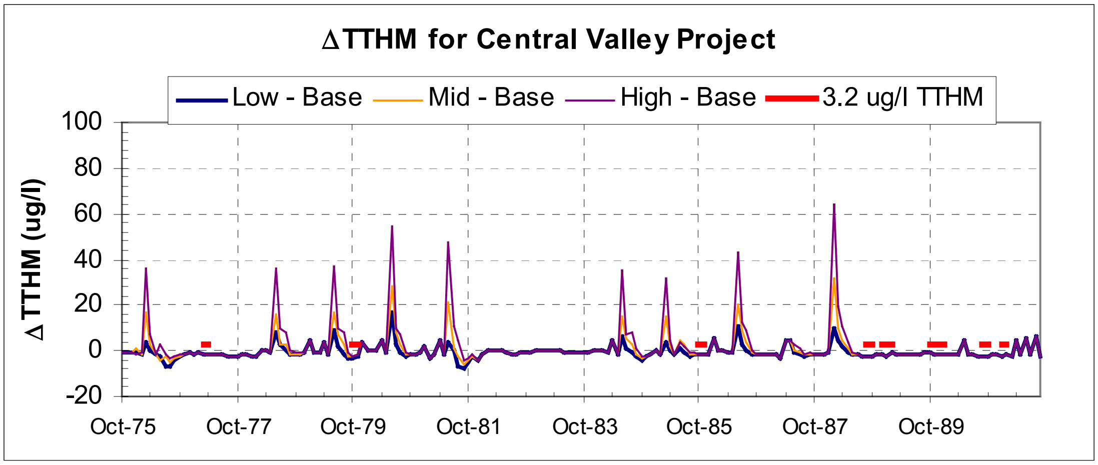


Figure 72: Time Series of Change in TTHM (Alternative – Base) for Central Valley Project.

4.6. Bromate (BRM)

According to the WQMP Bromate formation is limited 8 ug/l. For periods when the modeled base case exceeds this 8 ug/l standard, the WQMP permitted a 5% increase above the standard (0.4 ug/l) due to operation of the Delta Wetlands project.

Using EC and DOC for each of the DSM2 bookend simulations, bromate for Old River at Rock Slough was calculated as:

$$BRM = C_2 \times DOC^{0.31} \times Br^{0.73} \qquad \text{[Eqn. 8]}$$

where

BRM = bromate (ug/l),
C_2 = 9.6 when DOC < 4 mg/l,
C_2 = 9.2 when DOC ≥ 4 mg/l,
DOC = raw water dissolved organic carbon (mg/l) from DSM2, and
Br = raw water bromide from Equations 5 and 6.

Using Equations 6, 7, and 8, the bromate for all the urban intakes was calculated for the entire 16-year simulation period. The sensitivity to DOC release from the project islands is shown in Figures 73 – 80. Though bromate formation is a function of both DOC and bromide concentration, the bromide concentrations used to calculate bromate for each of the three DOC concentration levels were the same. The only differences between the three alternative scenarios occurred when water was released from the project islands, which typically occurred in the summer months (see Figure 2). As shown in Figures 73, 75, 77, and 79, the modeled base case bromate concentrations at all four intakes frequently exceeded the 8 ug/l WQMP standard during these release periods.

The maximum monthly bromate concentrations for each of the simulations are displayed in Table 15. For all four intake locations the operation of the project did not increase the maximum monthly bromate concentration. However, it is important to remember that there are still increases associated with the summer releases discussed above, thus the usefulness of this absolute time series plots and monthly maximum values are limited.

Table 15: Maximum monthly averaged bromate (ug/l) concentrations.

Location	*Base*	*Low*	*Mid*	*High*
Old River at Rock Slough	22.14	21.83	21.83	21.83
Old River at Los Vaqueros	20.54	20.26	2026	20.26
State Water Project	18.26	18.07	18.07	18.07
Central Valley Project	17.62	17.46	17.46	17.46

Time series plots (see Figures 74, 76, 78, and 80) illustrating the change between each alternative scenario and the base case provide a more useful tool to assess the impact of the project operation on bromate formation. Although these plots show the change due to project operation over the entire simulation period, the intermittent 0.4 ug/l maximum increase in bromate standard applies only at the times when the regular 8 ug/l WQMP standard was exceeded by the base case as discussed above. The maximum monthly increase in bromate when this second WQMP standard controls is listed in Table 16.

The bromate concentration at all four intake locations exceeded the WQMP 0.4 ug/l maximum increase standard several times due to the project operation. As listed in Table 16, the largest increase occurred at the Old River at Rock Slough intake location in December 1979. It is important to note that during this month water was diverted to the project islands (see Figure 1) which resulted in salinity in the a difference in salinity of over 200 umhos/cm between the alternative scenarios and the base case (see Figure 17). Increases in bromate concentration at Rock Slough also occurred in the winters of 1985, 1986, and 1988, all of which correspond with both periods of high salinity intrusion into the Central Delta and diversions into one or both of the project islands.

Table 16: Maximum monthly increase in bromate (ug/l) when base scenario was greater than the WQMP 8 ug/l standard.

Location	*Low – Base*	*Mid - Base*	*High - Base*
Old River at Rock Slough	1.69	1.69	1.69
Old River at Los Vaqueros intake	1.36	1.36	1.37
State Water Project	1.02	1.02	1.03
Central Valley Project	0.97	0.97	0.97

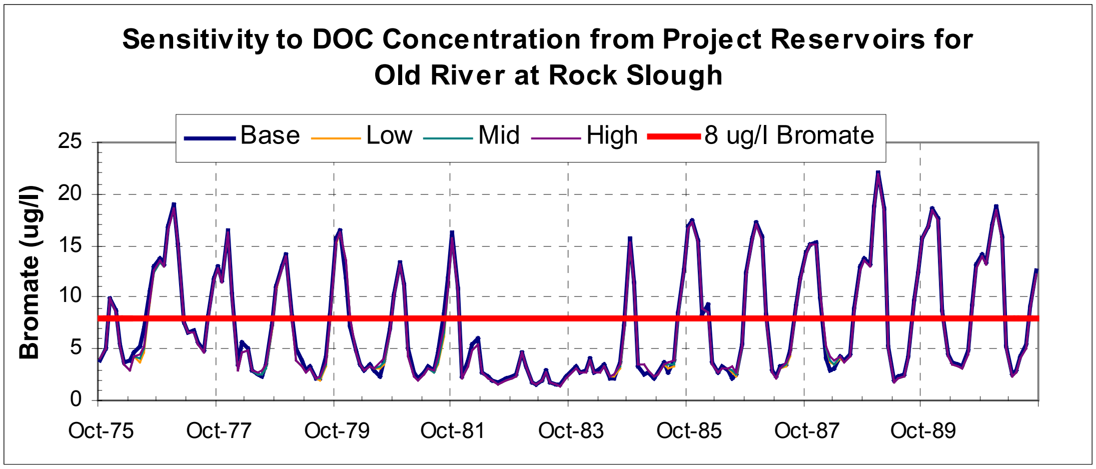


Figure 73: Time Series of Bromate Formation for Old River at Rock Slough.

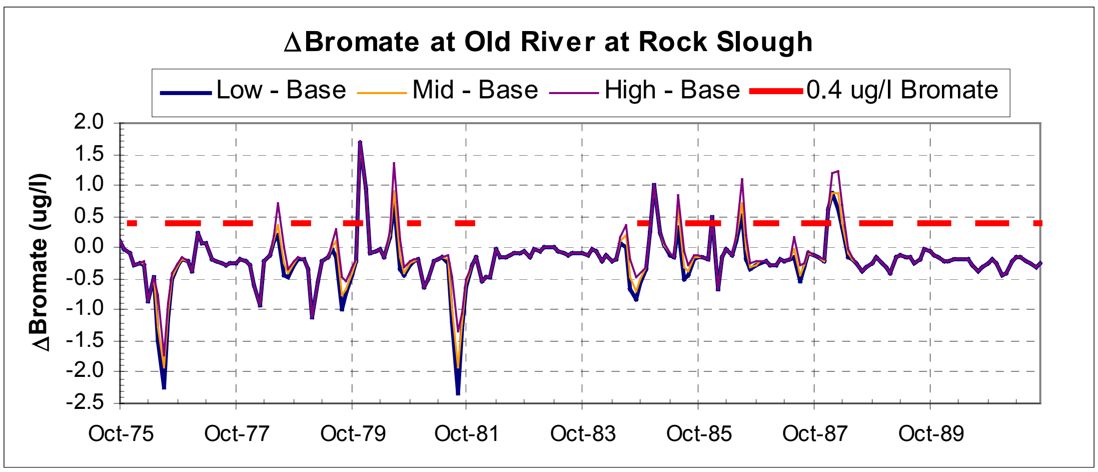


Figure 74: Time Series of Change in Bromate (Alternative – Base) for Old River at Rock Slough.

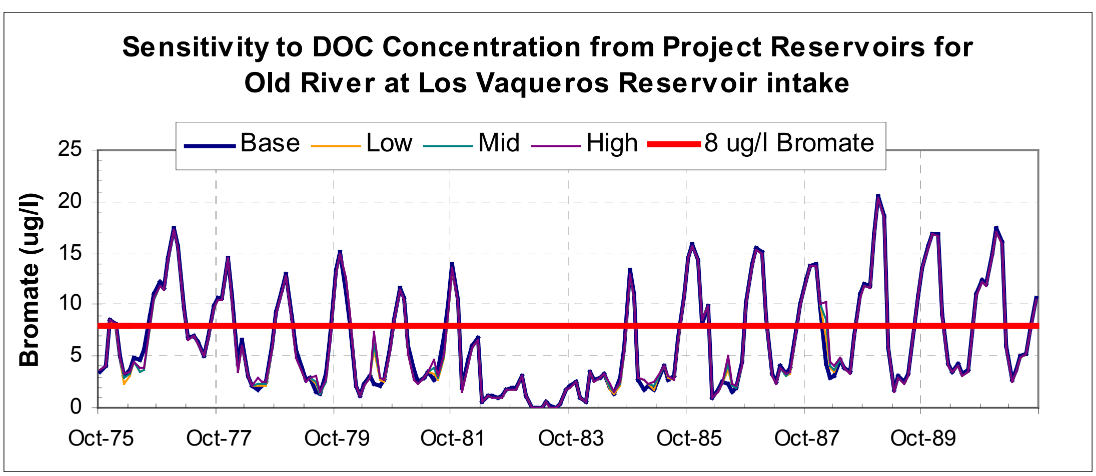


Figure 75: Time Series of Bromate Formation for Old River at Los Vaqueros intake.

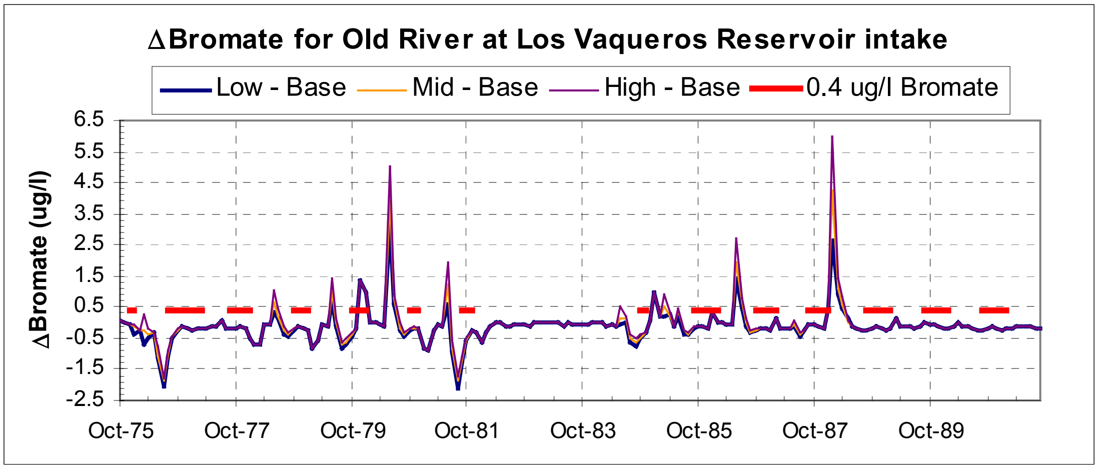


Figure 76: Time Series of Change in Bromate (Alternative – Base) for Old River at Los Vaqueros intake.

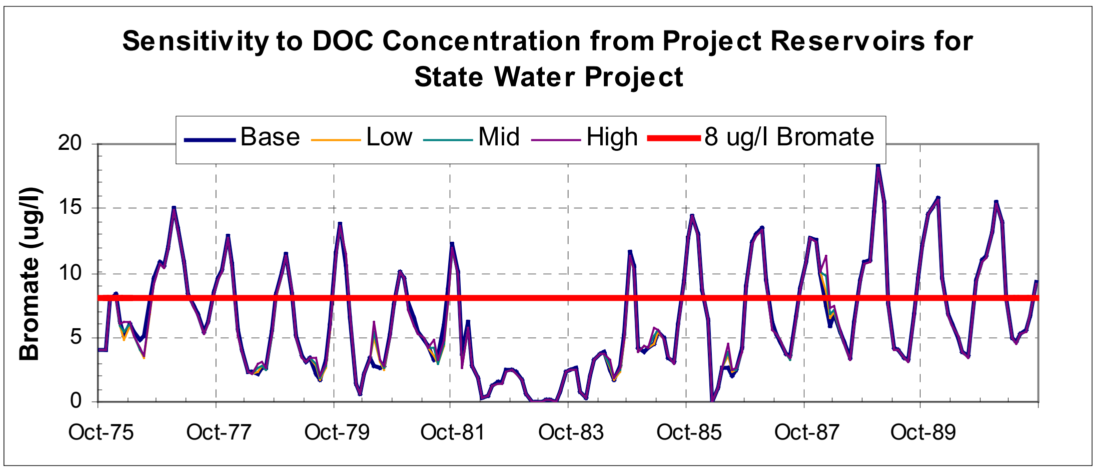


Figure 77: Time Series of Bromate Formation for State Water Project.

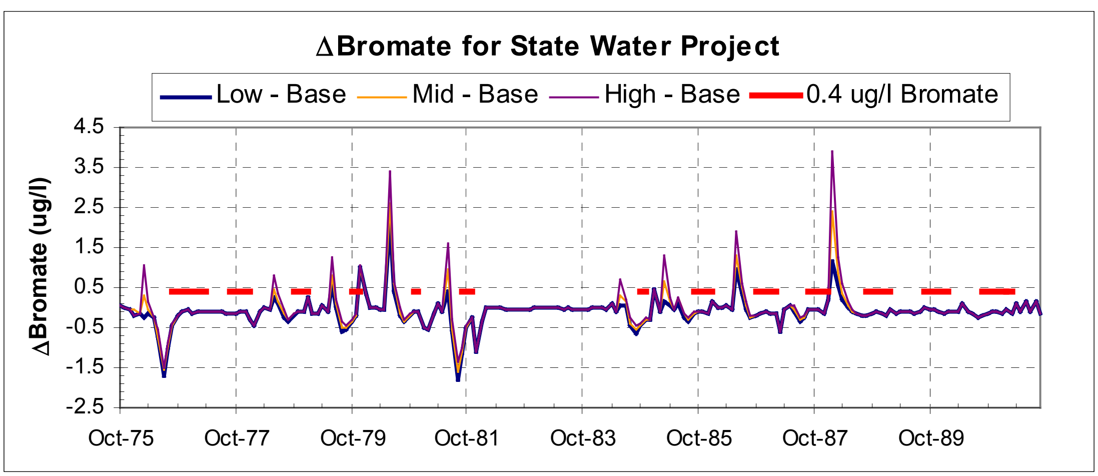


Figure 78: Time Series of Change in Bromate (Alternative – Base) for State Water Project.

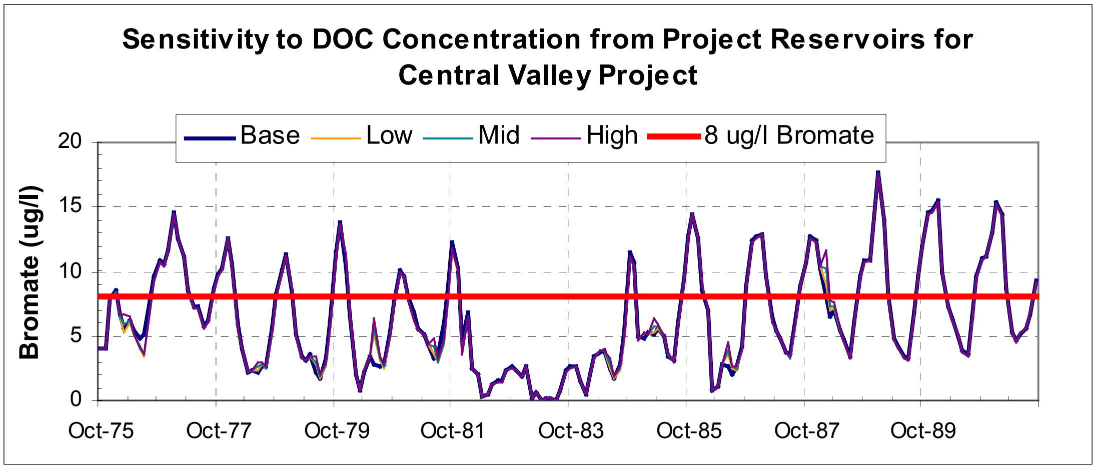


Figure 79: Time Series of Bromate Formation for Central Valley Project.

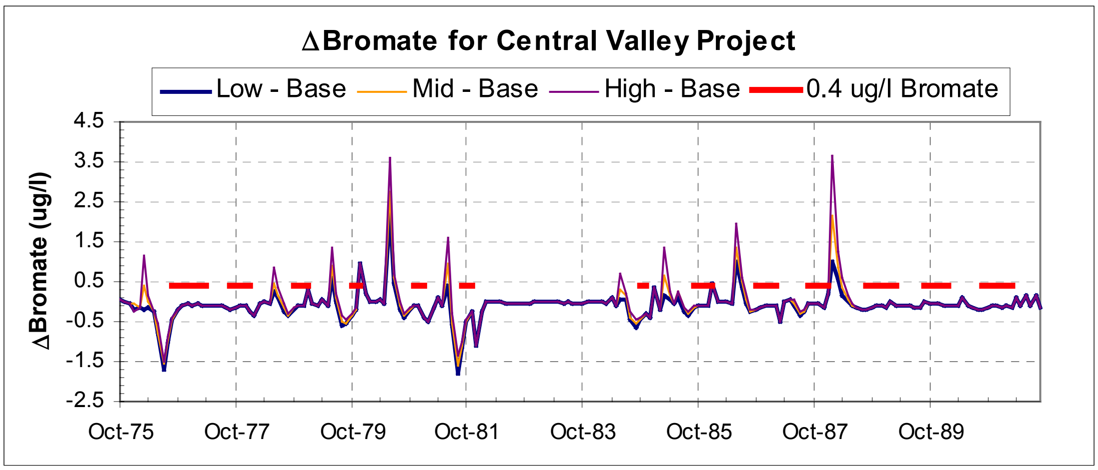


Figure 80: Time Series of Change in Bromate (Alternative – Base) for Central Valley Project.

5. Conclusions

- The DWRSIM 771 base case hydrology exceeded the Rock Slough Chloride standard nearly every winter during the 16-year simulation period with the exception of 1982 and 1983. Therefore the modeled EC at the four urban intakes is suspect for the Delta Wetlands alternative. It is recommended that a more accurate base case hydrology be used in future DSM2 studies.

- There was little difference in modeled EC between the base and Delta Wetlands alternative. The EC concentration of the water released from the project islands is a function of the quality of the water diverted on to the islands. Since TTHM and BRM formation are highly dependent on bromide concentration (which was calculated using EC), care must be taken when diverting water into the project islands in order to manage the EC, TTHM, and BRM impacts of the project islands.

- DSM2 simulated the project islands releases using three fixed concentrations at the discharge locations. QUAL did not consider the residence time of the water stored in the project islands. For future studies QUAL will be modified in order to better simulate the impact of storing water in the project islands for extended periods.

- The benefit of reducing the return of water from Bacon Island and Webb Tract on DOC, referred to as the *DOC ag credit*, ranged between 0 – 0.3 mg/l for Old River at Rock Slough. This *DOC ag credit* was less significant at the other three intake locations.

- The DSM2 DOC base case frequently exceeded the 4 mg/l DOC standard at all four intake locations during the late winter runoff periods.

- The mid- and high- DOC concentration releases from the project islands (which typically occurred in the summer) exceeded the 4 mg/l DOC standard. The increased DOC observed in DSM2 at the intakes ranged from around 3 – 4 mg/l at Rock Slough to an 8 mg/l increase at the Los Vaqueros intake on the Old River.

- Though the low DOC concentration release from the project islands did not exceed the 1 mg/l increase standard stipulated by the Delta Wetlands WQMP, this 6 mg/l DOC release approached the standard at the Los Vaqueros intake on the Old River.

- The long-term DOC trend (based on 3 year running averages) consistently showed the low-DOC concentration release scenarios to decrease the DOC mass loading at all four urban intakes. The mid- and high-DOC concentration release scenarios all exceeded the WQMP 5% increase in DOC mass loading limit.

- Los Vaqueros is the most sensitive intake location for both short- and long-term DOC. Future studies will model the discharge location for Bacon Island further to the east along the Middle River, which may reduce the DOC loading at Los Vaqueros due to project releases.

- UVA showed trends similar to those discussed above for DOC. The *UVA ag credit* was relatively small at all of the intake locations (less than 0.02 1/cm). Los Vaqueros is the most sensitive intake location. However, UVA is a factor in TTHM formation, thus it should still be modeled in future DSM2 simulations.

- The DWRSIM 771 hydrology, which was used as input for HYDRO, did not separate the diversions / exports between Contra Costa's Old River at Rock Slough intake and its' Los Vaqueros intake. The intake also lies between Bacon Island and the SWP and CVP intakes on the Old River. Even without modeling any exports from this location, the Los Vaqueros intake showed the most sensitivity to both DOC and UVA. For future studies it is recommended that operating rules be devised so that CALSIM can represent the diversions / exports at the Los Vaqueros intake.

- Since TTHM and BRM formation is highly dependent upon bromide, and even in the base case the Rock Slough chloride standard was exceeded, the TTHM and BRM calculated concentrations are suspect. When DSM2 is run again with improved operating conditions, TTHM and BRM relationships for the other intake locations will be developed and the formation of TTHM and BRM at all the intake locations will be revisited.

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APPENDIX A: Diversion and Release Schedule for Preliminary Delta Wetlands DSM2 Study

Jones and Stokes consultants originally created the preliminary diversion and release schedule for the Delta Wetlands project islands: Bacon Island and Webb Tract. This schedule lumped the total storage, diversions, and releases for both islands into one value per time step. A sample of these original values is shown as the gray columns in Figure A1 below.

DSM2 required that the flows into and out of the project islands be divided. Although the Jones and Stokes data included combined diversions and exports (releases), these flows did not balance the combined target storage for the two islands in many of the time steps. It is likely that this difference was due to the modeling of some sink term such as evaporation in the Jones and Stokes study. DSM2 does not account for evaporation or channel losses, thus it was decided that the combined target storage amounts would be used to build a new schedule, see Figure A1.

						<1>	<2>	<3>	<4>	<5>	<6>	<7>	<8>	<9>	<10>	<11>	<12>	<13>	<14>	<16>
						Change in	Target Storage		Target Max Flows		Change in Storage		Required Flows		Excess After		Releases		DSM2 Flows 1 intake	
Water Year	Month		Delta Storage (TAF)	Delta Storage Diversion (cfs)	Delta Storage Export (cfs)	Storage (TAF)	Bacon Storage (TAF)	Webb Storage (TAF)	Bacon Max Diversion (cfs)	Webb Max Diversion (cfs)	Bacon Storage (TAF)	Webb Storage (TAF)	Bacon Diversion (cfs)	Webb Diversion (cfs)	Bacon Diversion (cfs)	Webb Diversion (cfs)	Bacon (cfs)	Webb (cfs)	Bacon (cfs)	Webb (cfs)
87	OCT	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NOV	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	DEC	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	JAN	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	FEB	30	45	806	0	45	45	0	746	0	45	0	746	0	60	60	0	0	373	0
	MAR	30	43	25	0	-2	0	43	0	713	-45	43	-746	713	771	58	0	0	0	356
	APR	30	39	0	0	-4	0	39	0	646	0	-4	0	-66	0	66	0	0	0	0
	MAY	30	33	0	0	-6	0	33	0	547	0	-6	0	-99	0	99	0	0	0	0
	JUN	30	0	0	432	-33	0	0	0	0	0	-33	0	-547	0	115	0	432	0	0
	JUL	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	AUG	30	4	60	0	4	4	0	66	0	4	0	66	0	-6	-6	0	0	33	0
	SEP	30	0	0	0	-4	0	0	0	0	-4	0	-66	0	66	66	0	0	0	0
88	OCT	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NOV	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	DEC	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	JAN	30	184	2,999	0	184	120	64	1989	1061	120	64	1989	1061	1010	-51	0	0	995	530
	FEB	30	68	0	2,000	-116	0	68	0	1127	-120	4	-1989	66	1989	-77	1989	11	0	33
	MAR	30	0	0	1,052	-68	0	0	0	0	0	-68	0	-1127	0	75	0	1,052	0	0
	APR	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MAY	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	JUN	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	JUL	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	AUG	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SEP	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure A1: Spreadsheet used to calculated DSM2 diversion and release schedules.

A set of operating rules was described in Table 2 of the *Delta Wetlands Preliminary DSM2 Studies* report. Essentially this set of rules can be described as a "first on, first off" process. This type of operating rule requires keeping track of net changes in storage. Since the combined delta storage was considered fixed, changes in storage (in TAF) were calculated for each time step for column <1>. When the net change was increasing, operating rule 1 (fill Bacon to 120 TAF) was applied. When the net change was decreasing, operating rule 2 (use Bacon first –or– keep Webb at 118 TAF) was applied.

The target storage for each island was divided based on which operating rule was being applied (as determined from <1>). The following logic was used to determine exactly how much water should be stored in Bacon Island for column <2>. If the net change calculated in <1> is positive, then the islands are filling. If the combined Delta storage is less than 120 TAF (the capacity of Bacon Island), then fill Bacon to that amount. Otherwise, the combined storage is above 120 TAF, so both islands should be filled. Bacon will be filled to capacity, and the excess water should be placed in Webb Tract. If the net change calculated in <1> is negative, then the islands are releasing. If the combined Delta storage is less than 118 TAF (the capacity of Webb Tract), then Bacon should be completely empty and the remaining difference should come from Webb Tract. Otherwise, the storage is above 118 TAF, so the releases will only need to come from Bacon Island.

Using the combined Delta Storage given by Jones and Stokes and the target storage amount for Bacon Island <2>, the difference between the two is the target storage for Webb Tract <3>.

DSM2 uses flow rates instead of storage volumes, so each planning month storage was converted from TAF into cfs using Formula A1. A planning month of 30 days was assumed for this calculation.

$$Flow = \frac{Storage \times 1000}{days\, in\, month \times 1.9834} \qquad \text{[Eqn. A1]}$$

The flows that would be required to completely fill Bacon Island <4> and Webb Tract <5> if each were empty were calculated using Equation A1.

The change in Bacon Island <6> and Webb Tract <7> storage of the current month from the previous month was calculated for each island. These storage amounts represent the actual required flows for each island. Equation A1 was used again to convert the total required Bacon Island diversion <8> and total required Webb Tract diversion <9>.

The original Jones and Stokes study did provide estimates of diversions and releases into the combined island system. The excess flow based on storage requirements between this given value and the required Bacon Island diversions was calculated in column <10>. By doing this, Bacon Island should exactly meet the storage requirements as determined by the Jones and Stokes operating rules and there would be no accumulation or loss in water mass over the period of study.

The excess flow calculated in <10> was then used to fill Webb Tract, however the excess water that is not accounted for in DSM2 needed to be accounted for. The difference between the required Webb Tract diversion and this flow excess was calculated in <11> and labeled as the Excess flow after Webb Tract diversion. This difference was then converted into a time series and treated as a mass balance correction time series (it would act either as a source or sink term applied directly to Webb Tract in order to prevent the island from overflowing over the period of the study).

The releases from Bacon Island <12> were also calculated based on changes in total storage. Again, applying the logic of the Jones and Stokes operating rules (see Table 2), the following logic was used to create DSM2 release schedules. When there is a release in the original study (i.e. a positive delta storage export), then the change in storage for Bacon Island, column <6> was multiplied by –1 and converted into flows using Equation A1. The releases from Webb Tract <13> were calculated as the difference between the Bacon Island releases and the Jones and Stokes scheduled releases. NOTE: Changes in the storage of Webb Tract were not used, because the diversions into Webb Tract were based on flow differences and not target storage amounts. Since a source / sink term was added to account for the differences between inflow and target storage, the same accounting technique needed to be used to remove water from Webb Tract.

The inflows for each islands' intakes were taken to be ½ of each islands required inflow. For example, Bacon Island's intake inflows <14> were simply ½ of the Bacon Island required diversion <8>; and Webb Tract's intake inflows <16> were ½ of the Webb Tract required diversion <9>.

OFFICE MEMO

TO: Paul Hutton	DATE: December 3, 2001
FROM: Tara Smith	SUBJECT: Updated Delta Wetlands Preliminary DSM2 Studies

I. Introduction and Summary

The Delta Wetland Delta Simulation Model 2 (DSM2) Simulations (Mierzwa, 2001) were rerun by Michael Mierzwa with the following changes:

1. Only the Dissolved Organic Carbon (DOC) water quality constituent was modeled.
2. The simulations were run using a 1995 level of development. The previous simulations used a historical level of development.
3. The habitat islands' drainage and diversions were modeled. The previous simulations modeled the habitat islands as agricultural islands.
4. The Sacramento and San Joaquin DOC boundary values were adjusted to reflect the relationship between DOC and high winter flows. (Suits, Nov 2001)
5. The hydrodynamic simulations were made using a real tide that includes the spring and neap cycle. The previous simulations used a 19 year repeating tide.
6. The DOC concentrations released from the project islands were modeled in a different way. The 6, 15, and 30 mg/l release qualities that occurred in the original simulations were not modeled again. Instead, the carbon growth module developed by Marvin Jung (Jung, 2001) and implemented into DSM2 (Pandey, 2001) was used to model variable release qualities with two bookend maximum DOC levels.
7. The exports were increased to include the water that is released from the reservoir islands. In the previous simulations, the exports for the base and the Delta Wetlands operation were identical.
8. Water diverted by Contra Costa Water District was separated between the Contra Costa Canal Intake and the Los Vaqueros intake. Contra Costa Water District provided this division of the diversion to DWR. Diversion water was only taken through Contra Costa Canal in the original simulations.
9. The diversion location for Bacon Island was changed from the middle of False River to the intersection of False River and Middle River.
10. Source tracking was done. Results are not presented in this memo.
11. Particle tracking was done for June and July of 1980. Results are not presented in this memo.

These simulations resulted in the following findings that are shown graphically in the following pages:
1. Maximum monthly DOC increased in base case.
2. Maximum monthly DOC for high bookend alternative decreased.
3. Low bookend DOC did exceed the maximum increase in DOC standard at the Los Vaqueros Reservoir intake.

II. DSM2 Input

The following graphs and figures show some of the major inputs to DSM2.

A. Inflows

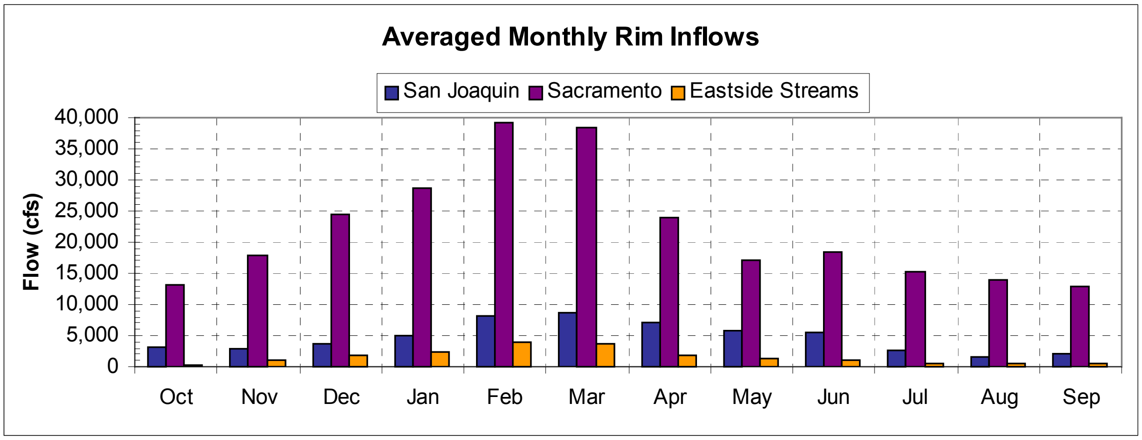


Figure 1

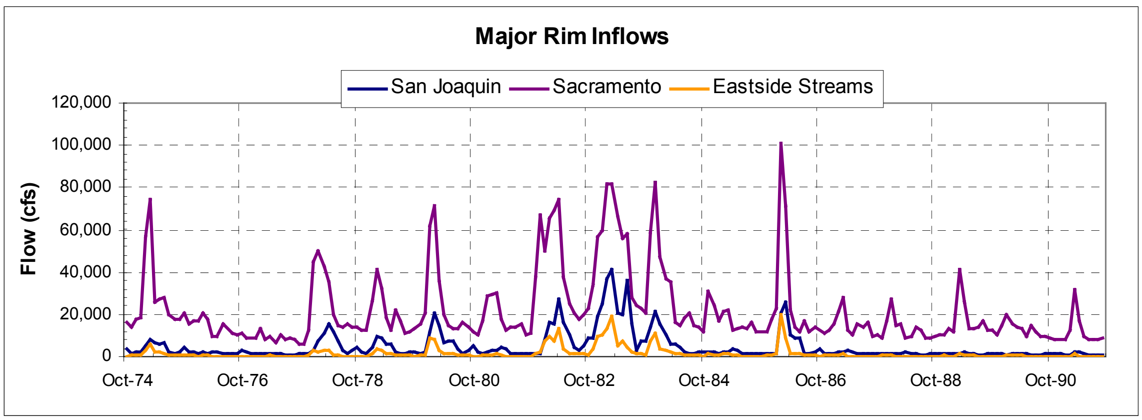


Figure 2

B. DOC Boundary Conditions

1. DOC for Rim Boundaries

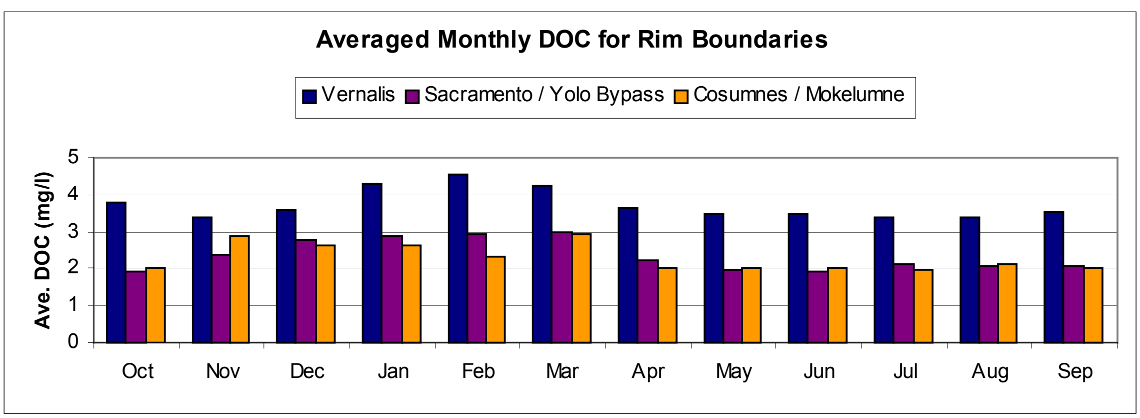


Figure 3

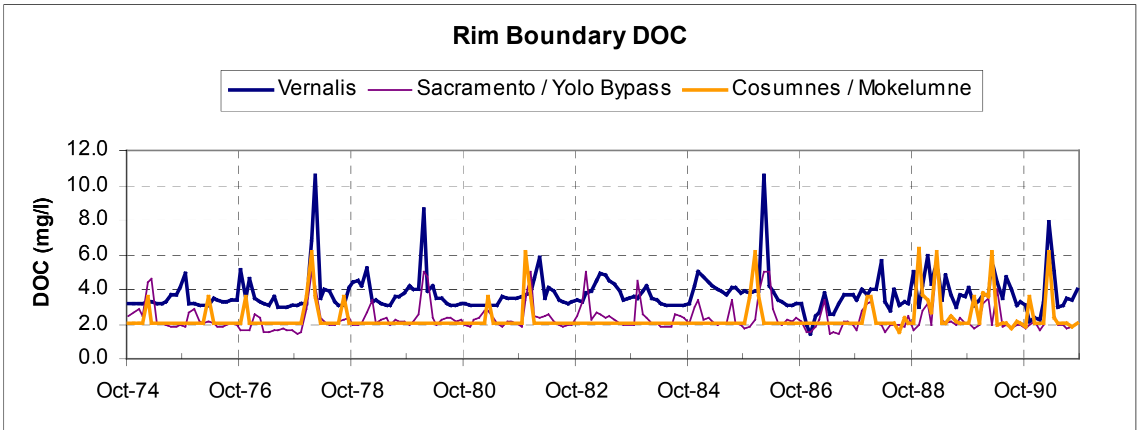


Figure 4

2. Agricultural Release DOC

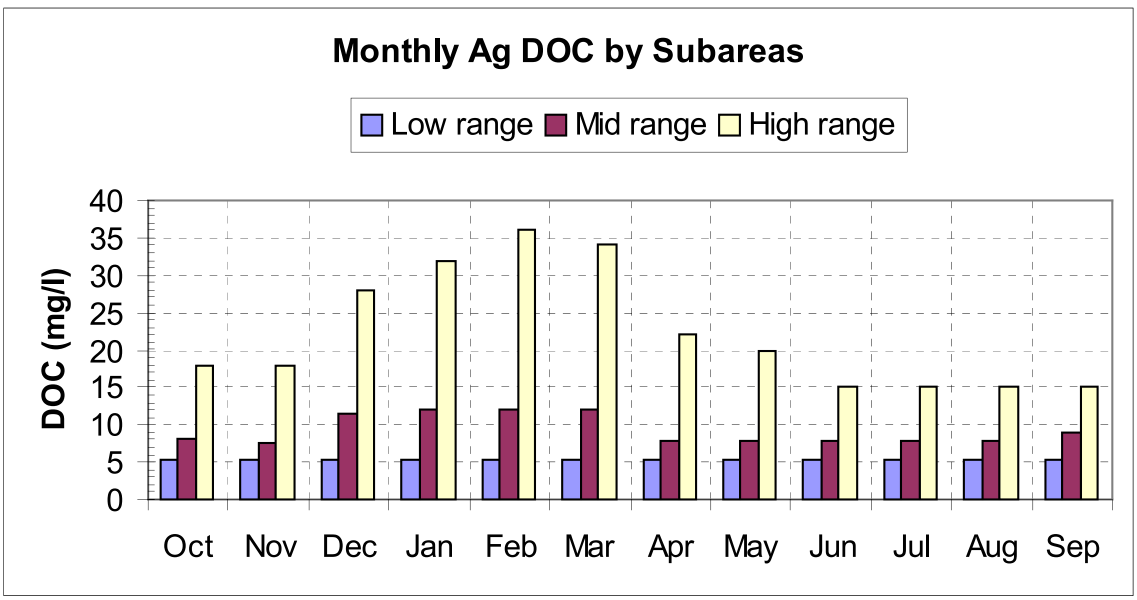


Figure 5

C. Diversions to and Releases from Islands

1. Diversions to Project Islands

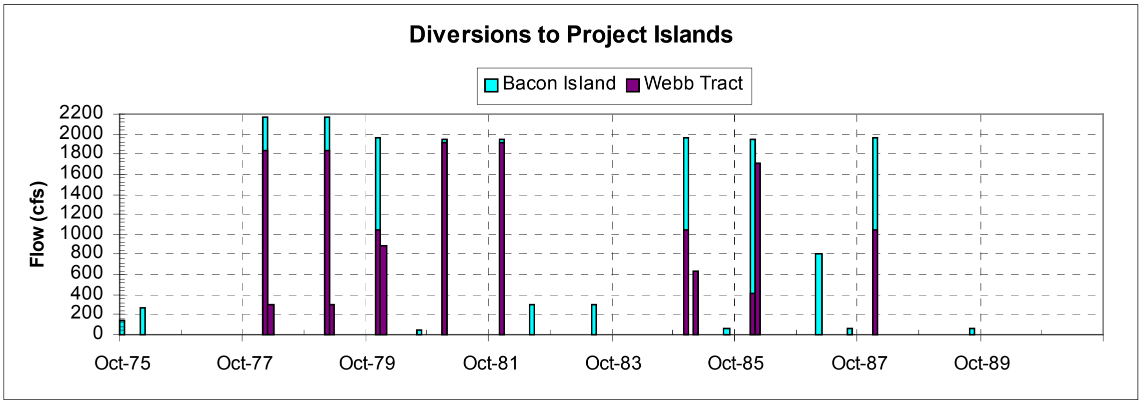


Figure 6

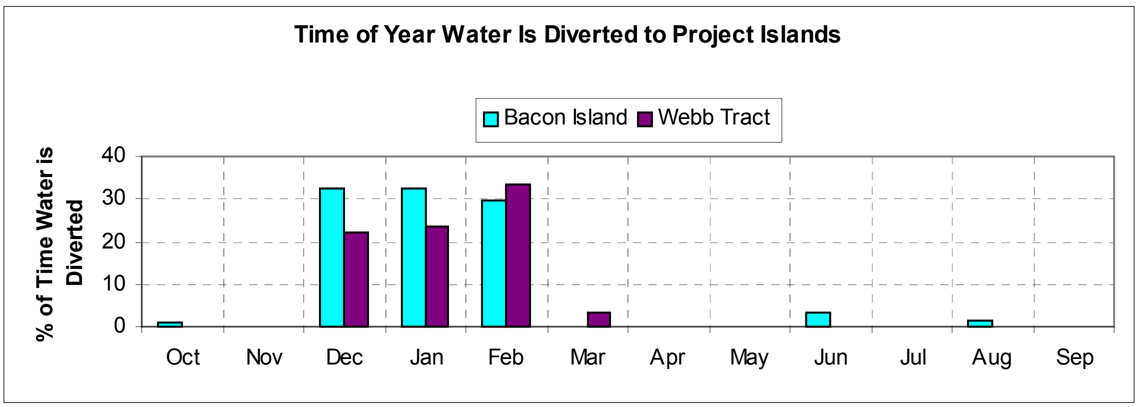


Figure 7

2. Releases from Project Islands

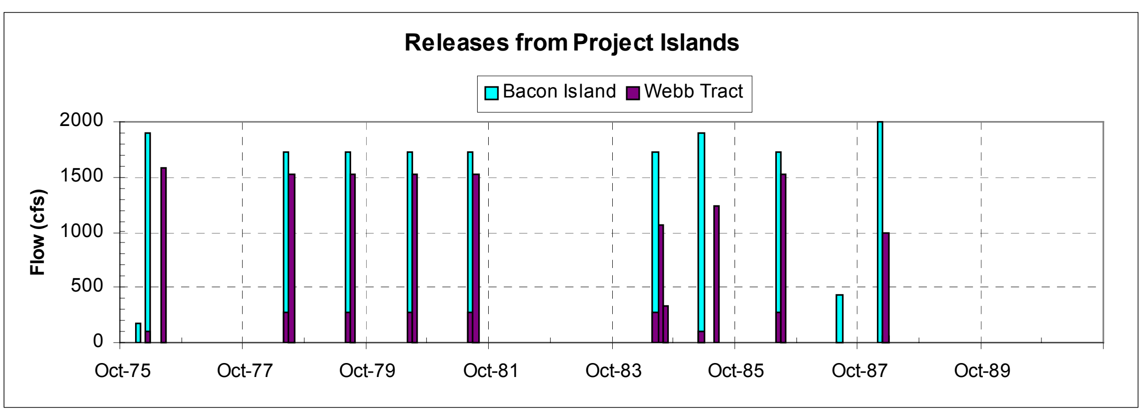


Figure 8

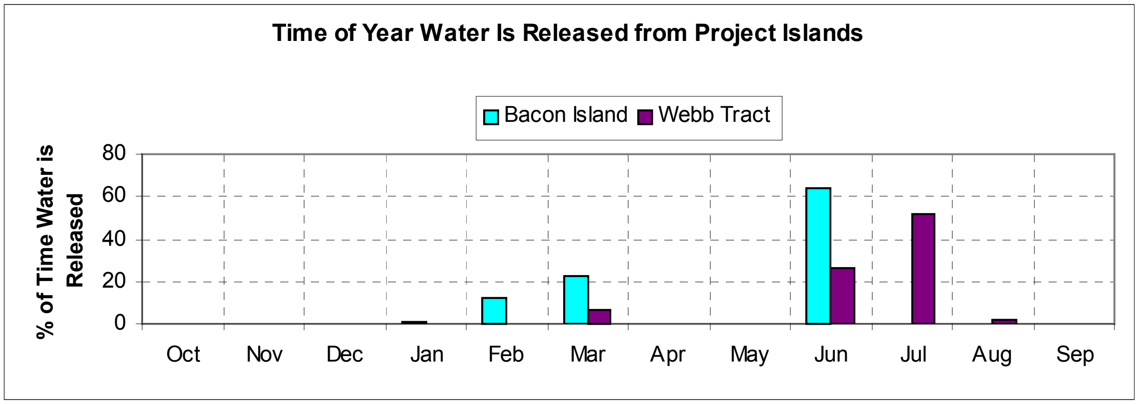


Figure 9

3. Habitat Island Consumptive Use

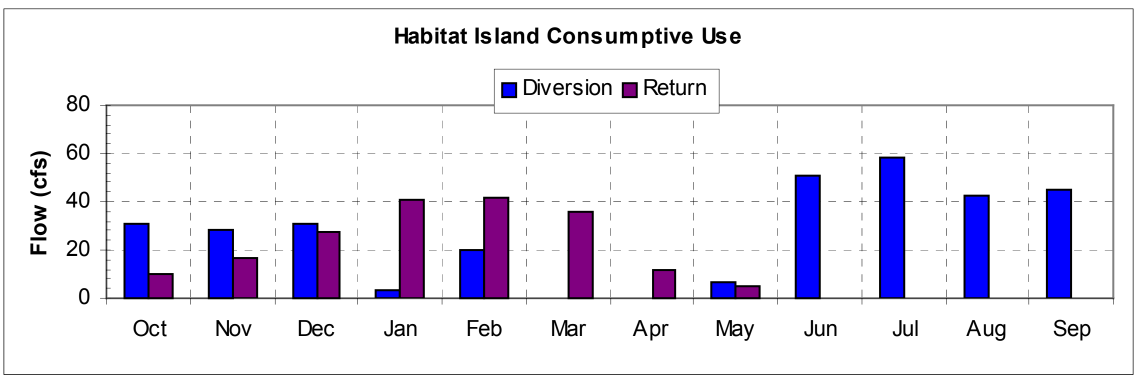


Figure 10

D. Location Maps of Island Diversions and Releases

1. Project Islands

Bacon Island

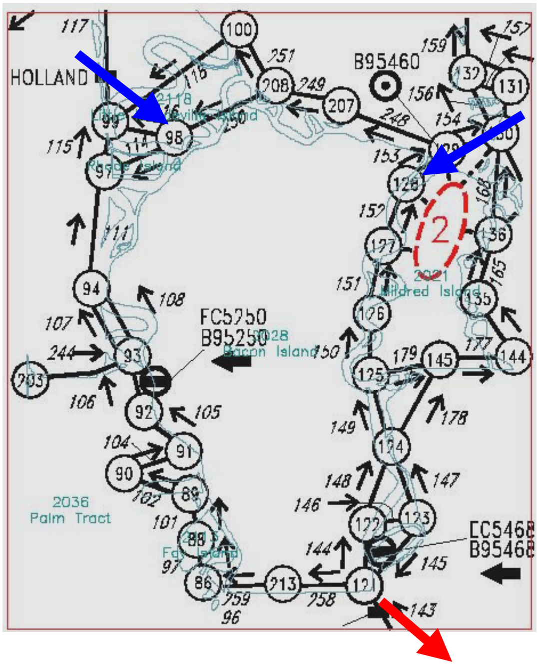


Figure 11

Webb Tract

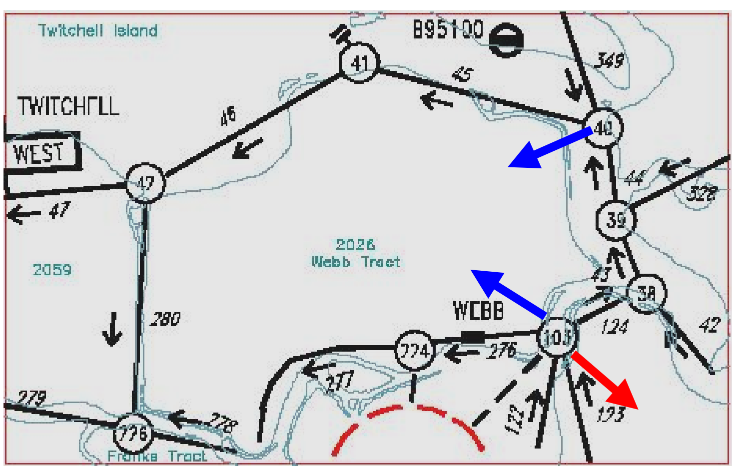


Figure 12

2. Habitat Islands

Bouldin Island

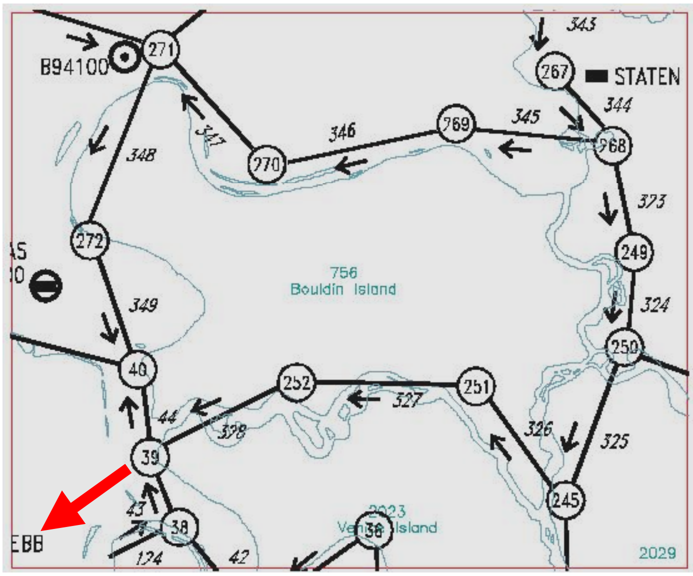


Figure 13

Holland Tract

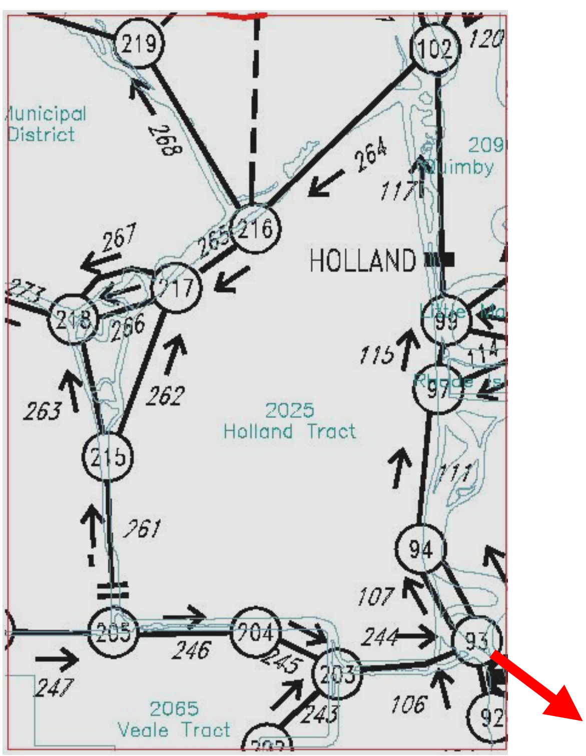


Figure 14

III. DSM2 Results

A. DOC at Old River at Rock Slough

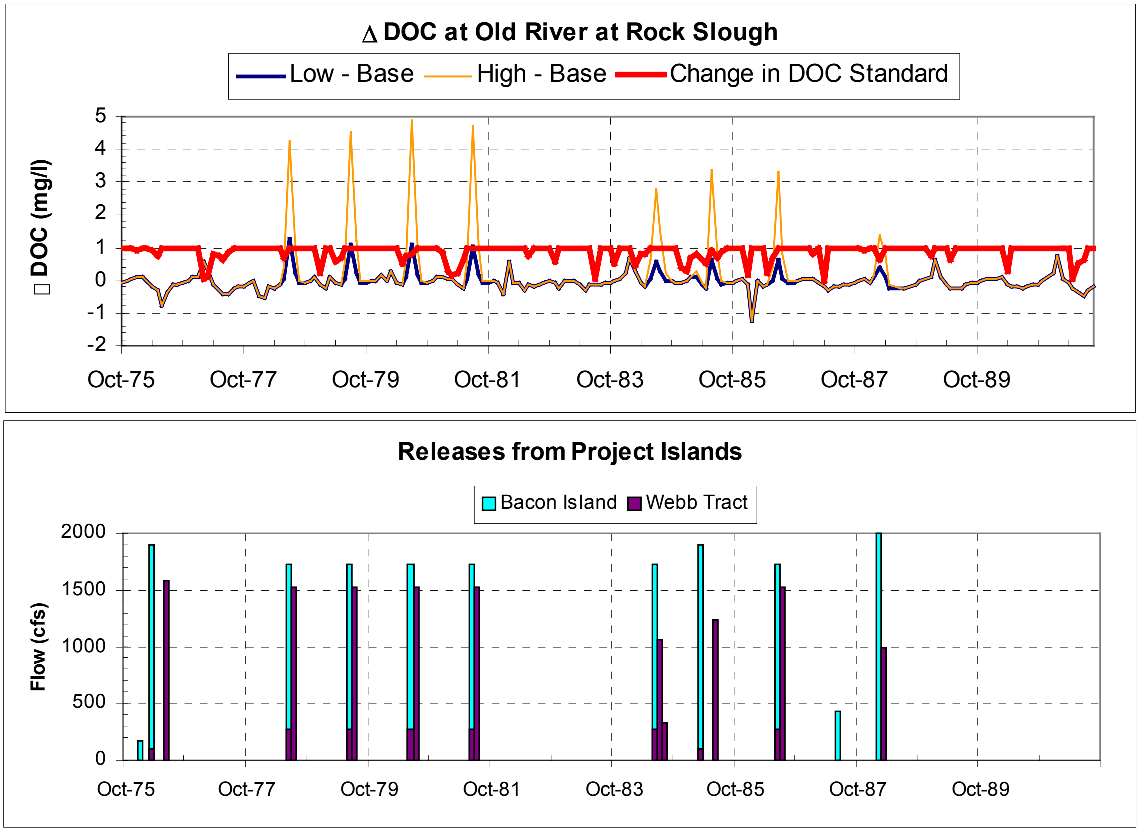
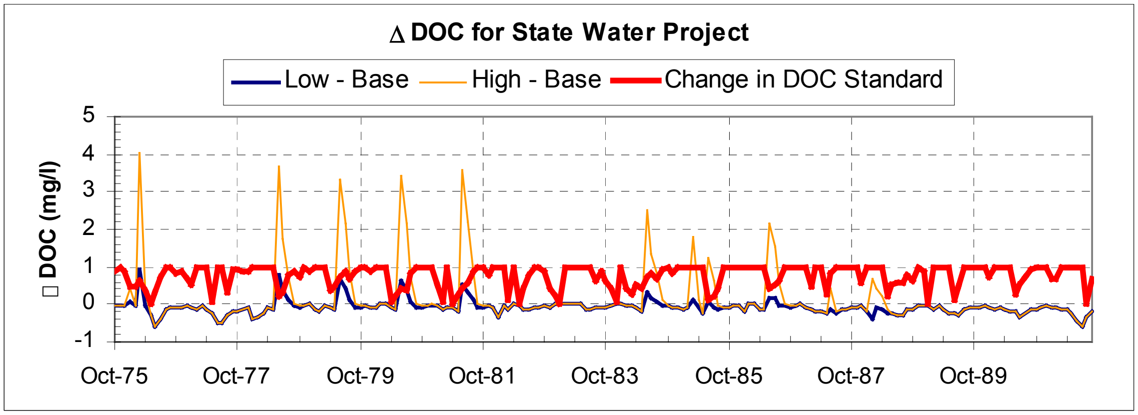


Figure 15

B. DOC at Old River at the SWP Intake



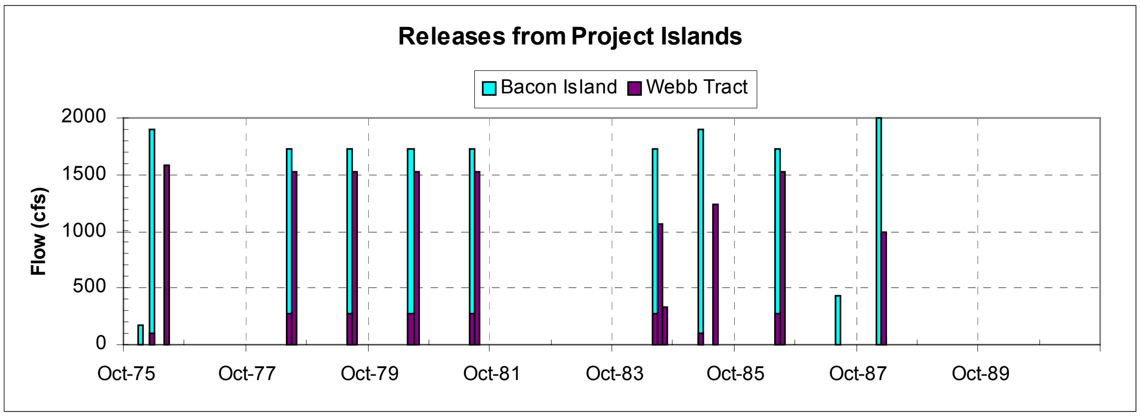
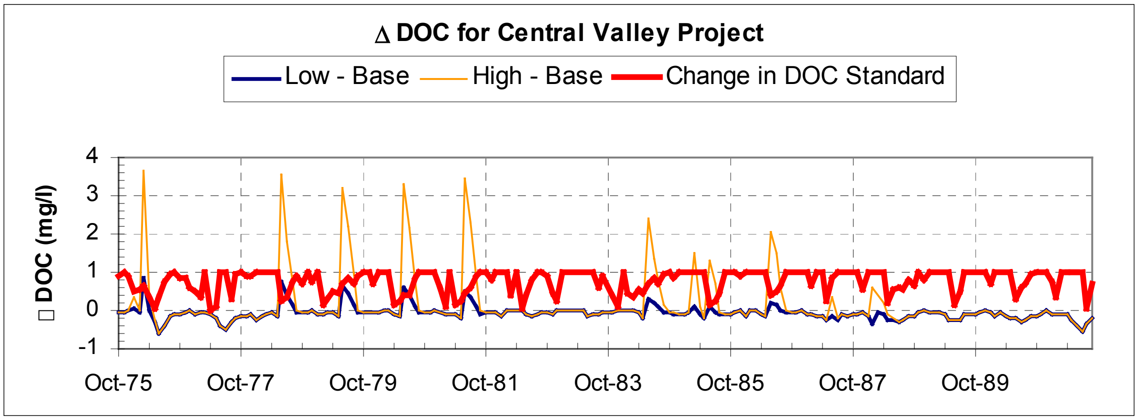


Figure 16

C. DOC at the Los Vaqueros Intake



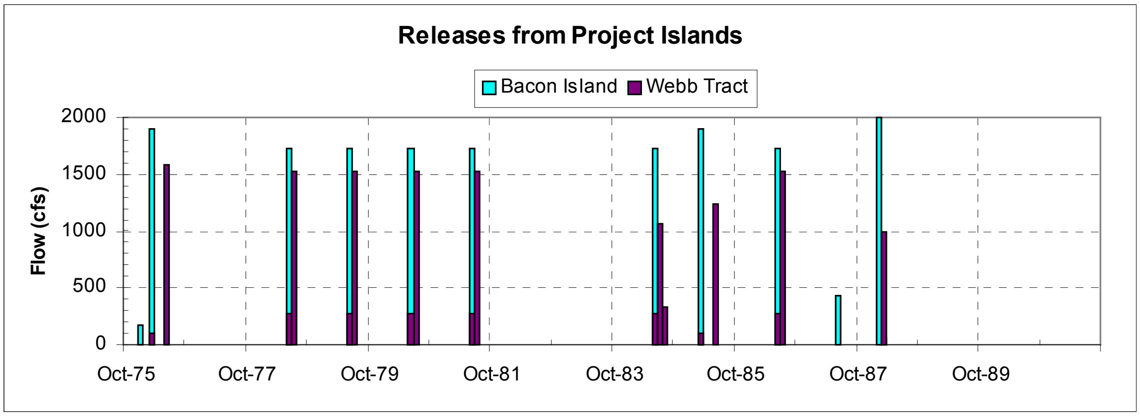


Figure 17

D. DOC at the Central Valley Project Intake

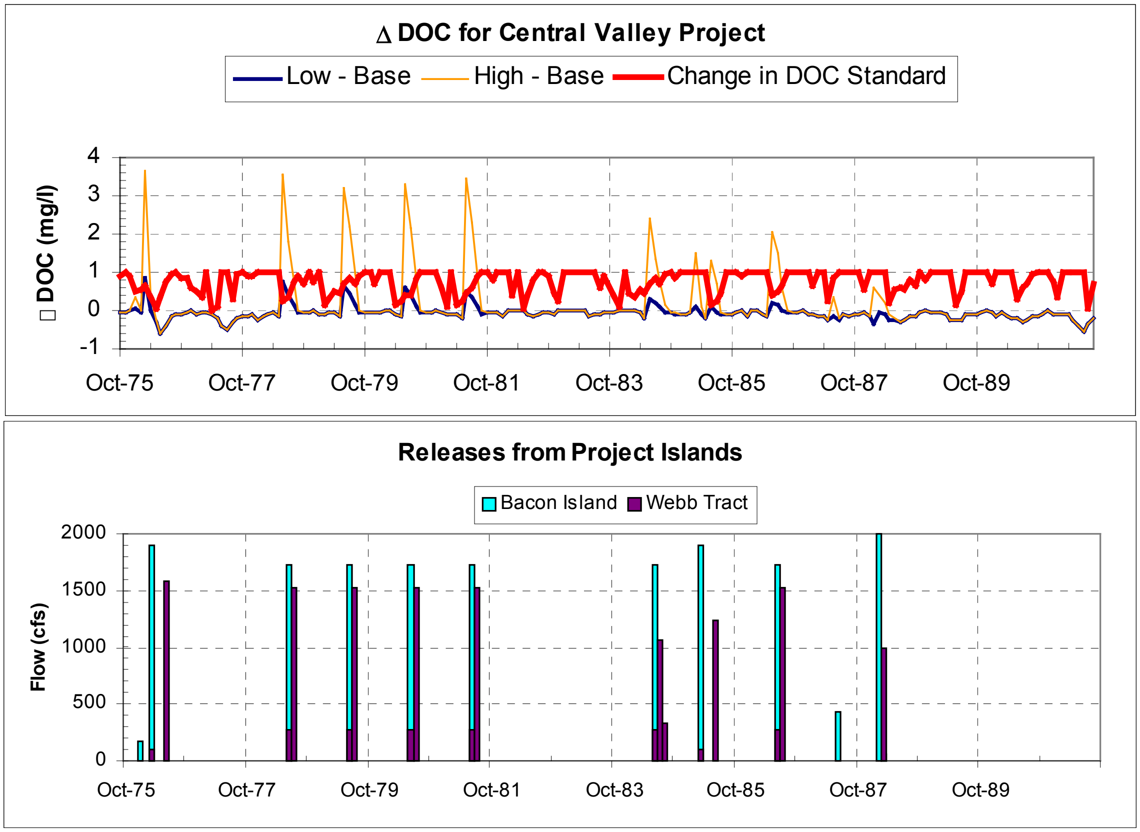


Figure 18

References:

Mierzwa, Michael. (August,2001). *Delta Wetlands Preliminary DSM2 Studies.* Memo to Tara Smith. California Department of Water Resources.

Suits, Bob. (Nov, 2001). *Boundary DOC and UVA for DSM2 Planning Studies.* Memo to Paul Hutton. California Department of Water Resources.

Pandey, Ganesh. (Nov, 2001) *Implementation of DOC Growth Module in DSM2-QUAL*. Memo to Parviz Nader. California Department of Water Resources.

OFFICE MEMO

TO: PARVIZ NADER	DATE: 11-19-01
FROM: Bijaya Shrestha	SUBJECT: Running DSM2 in Planning Mode Using Daily Varying Hydrology and Non-Repeating Tide

DWR Delta Modeling Section uses Delta Simulation model (DSM2) to simulate the hydrodynamics (flow and stage) and water quality (often measured in terms of Electric Conductivity, EC) in the Sacramento San-Joaquin Delta. Traditionally, under a 'Planning' mode setup, the Delta Modeling Section conducts a 16-year simulation, covering water years 1976 to 1991 using monthly average hydrology rim input. The rationale behind the selection of this period was discussed in detail in the CALFED report ("Status Reports on Technical Studies for the Storage and Conveyance Refinement Process", August 1997). The monthly average hydrology input is obtained directly from the output of CALSIM (the Statewide Operation Model). To simplify the procedures the following approach had been introduced:

1- A repeating tide (which is based on the 19-year mean tide) was used as the stage boundary condition at Martinez with a 25-hour cycle (See Delta Modeling Section's 2001 Annual Report, Chapter 9).

2- A separate DSM2-Hydro run was completed for each month. During each run, the hydrology was kept constant. The model run continued until a condition of dynamic steady-state was achieved.

3- The results (flow, stage, etc) were saved in a tide file (25 hour long). These conditions were assumed to repeat every day for the entire month.

The main reasons for following this approach was to reduce the CPU time and storage requirements.

Standard outputs generated from these simulations included monthly average net flows, monthly minimum water surface levels and monthly average EC.

In Delta Storage was the first project that required specification of daily varying hydrology. As such, it was obvious that the current setup could not handle this. Starting from early summer 2001, Delta Modeling Section initiated efforts to implement a new approach allowing for daily variation of hydrology. The following is a list of major changes required to implement the new approach:

1- Since the hydrology changes daily, DSM2- Hydro will be used to run every day of every month. With this approach instead of individual model runs (one per month), the entire 16-year simulation will be conducted in a single run.

2- A non-repeating tide at Martinez will be used as the stage boundary, since there are no benefits to be gained from using the "repeating tide" (See Delta Modeling Section's 2001 Annual Report, Chapter 10).

3- Previously, gate operations were specified on a monthly time-scale. The new approach allows specification of gate operation on a daily time scale (or even smaller time-scale if needed).

There are distinct advantages for using the new approach. The major advantage is that the new approach simulates conditions as close as possible to the way they are specified. The non-repeating tide captures spring and neap tides, which was not possible when the repeating tide was used. In addition, a much more complex analysis can be made possible using the output. One can go beyond reporting the monthly average flows, ECs, and monthly minimum water levels. As a result, Delta Modeling Section plans to have a totally new (possibly statistically based) output system. This is expected to be an ever-evolving process.

Table 1 highlights the major differences between the new approach versus the traditional approach. More details will be provided in the Delta Modeling Section's 2002 annual report.

Table 1: Comparison between the new approach versus the traditional planning run setup

Item	Category	Monthly hydrology with repeating tide	Daily hydrology with non-repeating tide
1	CPU Time	Takes approximately 16 hrs to complete a DSM2 Hydro and Qual run	Takes approximately 32 hrs to complete a DSM2 Hydro and Qual run
2	Disk space requirement	Needs about 250MB for Hydro binary tide file and outputs	Needs about 4GB for Hydro binary tide file and outputs
3	Ease of Computation	Easy to design model input as each run is separate for each month of a given year	Complex, need to design the run and input for entire simulation period
4	Accuracy	Accurate in monthly time period scale Only predicted monthly average output has any value. Monthly extreme values are based on the repeating tide, and therefore provide information of little value Gate operation can only be monthly scale	Accurate in daily time period scale Since non-repeating tide is used, spring and neap tidal effects are modeled and therefore extreme value analysis is possible. Gate operation can be continuous with any time scale.

OFFICE MEMO

TO: Parviz Nader	DATE: 11/19/01
FROM: Ganesh Pandey	SUBJECT: **Implementation of DOC Growth Module in DSM2-QUAL**

Background

The Municipal Water Quality Investigations (MWQI) Program of DWR conducted field experiments to determine the changes in DOC (dissolved organic carbon) concentrations due to water contact with peat soil. Based on these experimental findings, Jung (2001) proposed a set of logistic type equations to characterize the increase or "growth" of DOC on flooded Delta islands due to peat soil leaching and microbial decay. Due to concerns about disinfection byproduct formation during drinking water treatment, the Delta Wetlands Water Quality Management Plan restricts the amount of DOC impact at urban diversions resulting from Delta island storage releases. This restriction has created the need to assess impacts at urban diversion due to DOC growth on the flooded islands. This report summarizes the methodology used to implement Jung's proposed logistic equations in DSM2-QUAL.

Logistic Equation

The logistic equation proposed to simulate the concentration of DOC in flooded Delta islands due to initial concentration and growth is expressed as:

$$Y(t) = \frac{A}{1 + Be^{-kt}} \qquad (1)$$

where Y(t) represents the DOC concentration in mg/l at time t, "A" represents the maximum DOC concentration in mg/l, "k" is the growth rate in days^{-1} , and "t" is the water storage duration in days. "B" is a dimensionless parameter that is calculated from the initial DOC concentration. The values of "A" and "k" depend on reservoir specific characteristics, such as type and depth of the peat soil, antecedent flooding conditions, temperature, etc.

The magnitude of "B" is calculated by DSM2-QUAL. When t=0, Equation (1) simplifies to C_0 = A / (1+B), where C_0 is the initial DOC concentration of the water diverted to the reservoir. The value of C_0 is dynamically determined in DSM2. Knowing the values of C_0 and "A", the value of "B" can be computed. During the filling period, exchange of mass between peat soil and water body takes place starting with the first parcel of water entering the reservoir. Because the filling process is not instantaneous, the diversion water concentration changes over time. Thus, two aspects of DOC concentration change must be accounted for: (1) growth of DOC due to peat soil interactions and (2) conservative mixing of channel diversion water in the reservoir. The first aspect usually represents a gradual change, whereas the second aspect can potentially be an abrupt change, especially if the diversion water quality is highly variable. In order to model both aspects, "B" is adjusted each time step to account for the changes in DOC due to channel diversions. Once a filling cycle is completed, conservative mixing ends and "B" is held constant. During a draining cycle, "B" is held constant.

Depth Adjustment

All model parameters (A, B, and k) are specified with respect to a given reference depth which is currently set at 2 feet. To adjust DOC growth for varying water depths, Jung (2001) recommends an inverse power law transformation, as shown in Equation (2):

$$y_d = y_2\left(\frac{2}{d}\right)^{1.01} \qquad (2)$$

where y_d is the adjusted DOC concentration, y_2 is the DOC concentration per Equation (1) with model parameters based on a 2 feet water depth, and d is the actual water depth. During the first phase of model implementation, the water depth dynamically calculated in DSM2 was used to represent "d". However, it was discovered that during the early stages of the filling cycles, very low water depths resulted in unreasonably high DOC adjustments. As a possible remedy, "d" was set equal to the maximum water depth during each filling cycle. Maximum water depth is computed by the model; however, its value is not known until the end of each filling cycle. To work around this problem, a default value of 15 feet is used for "d" during the filling cycle until the actual water depth exceeds the default value. Once the default value is exceeded, the dynamically calculated value is used in Equation (2).

Timing of Filling and Draining

During each filling and draining cycle, it is assumed that the exchange of mass between peat soil and water body takes place immediately after the arrival of the first parcel of water. The value of t in Equation (1) must be initialized at the beginning of each filling cycle. Initiation of a filling cycle is defined by the diversion rate – the filling cycle begins when the diversion rate exceeds a certain default flow rate (currently set at 100 cfs). The DOC growth contribution from Equation (1) is curtailed once the storage depth becomes smaller than a minimum specified depth, currently set at 1.5 feet.

Results Using a Test Case

The DOC growth module was first tested within DSM2 utilizing a Delta Wetlands operations study (Mierzwa, 2001). In this study, Webb Tract and Bacon Island were used as storage reservoirs. In past efforts, the DOC concentration of island releases was predetermined using a "book-end" approach, with 6 mg/l as the lower limit and 30 mg/l as the upper limit. With the new DOC growth module, island release water quality is dynamically computed. Two model scenarios were conducted. In Scenario 1, the return quality was determined using the newly developed DOC module. Table 1 shows the model parameters used in Scenario 1. In Scenario 2, DOC was modeled as a conservative substance with no growth within the reservoirs. Differences between the two scenarios can be attributed to the growth term incorporated in the DOC module.

Table 1- DOC Module Input Parameters for Scenario 1

Storage Reservoir	A (mg/l)	k ($days^{-1}$)	Minimum Depth (ft)
Webb Tract	217	0.0216	1.5
Bacon Island	107	0.0256	1.5

Figure 1 compares the predicted DOC concentrations in the Webb Tract reservoir for the two scenarios for the period covering January 1979 to September 1981. The water exchange is also shown on the same plot. Model results follow the same path in the first filling cycle. Once the filling cycle is completed in March 1979, predicted values quickly diverge, illustrating the growth of DOC. The largest differences occur right before the beginning of the next filling cycle. Model results converge again with the start of a new filling cycle. The convergence and divergence cycles continue throughout the simulation period consistent with the operation schedule for the filling cycle. The peak DOC concentration in Scenario 1 approaches the value of "A", adjusted for depth using Equation (2).

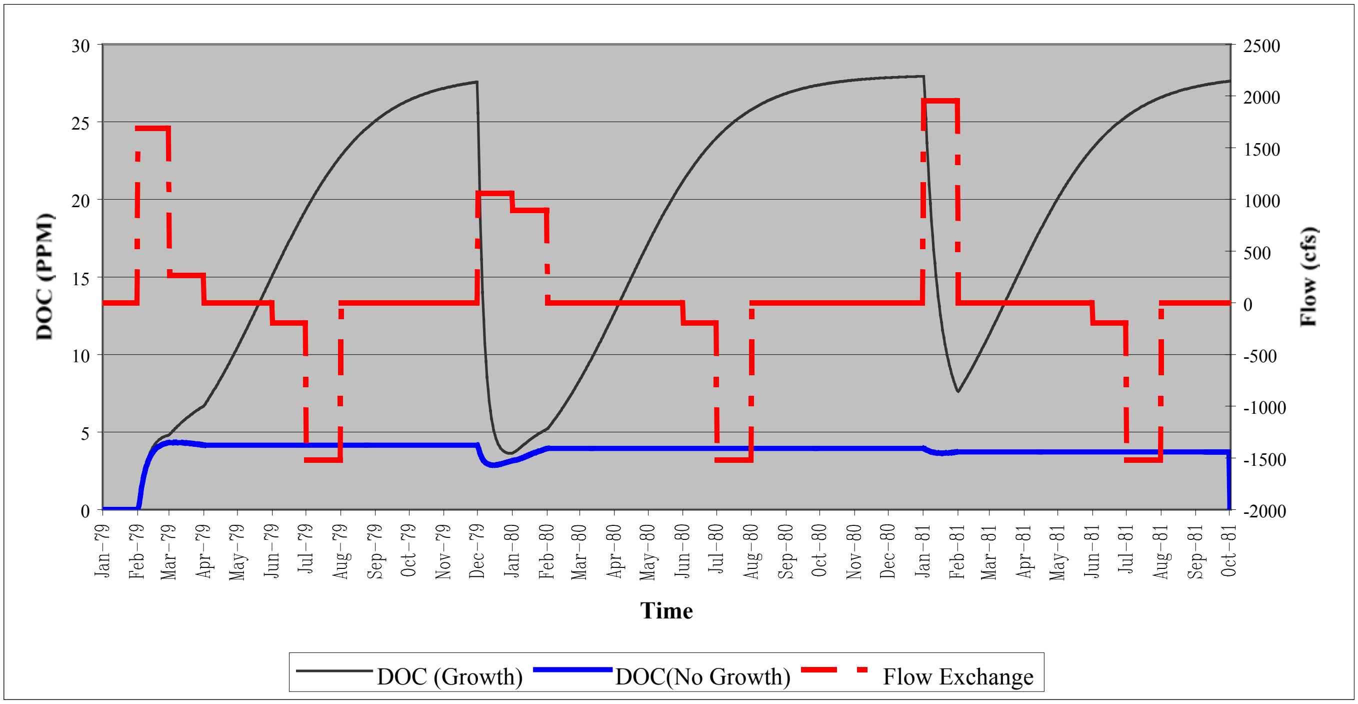


Figure 1: Time series plots of DOC concentrations and flow exchange on Webb Tract. The positive and negative flow values indicate filling and draining cycles, respectively.

Figure 2 shows a similar comparison of the predicted channel DOC values near the Webb Tract reservoir release site. Model results correctly predict that the DOC concentrations during the filling and storage cycles are very similar. The model results then diverge with the start of a draining cycle. The model results then start merging one to two months after the end of the draining cycle.

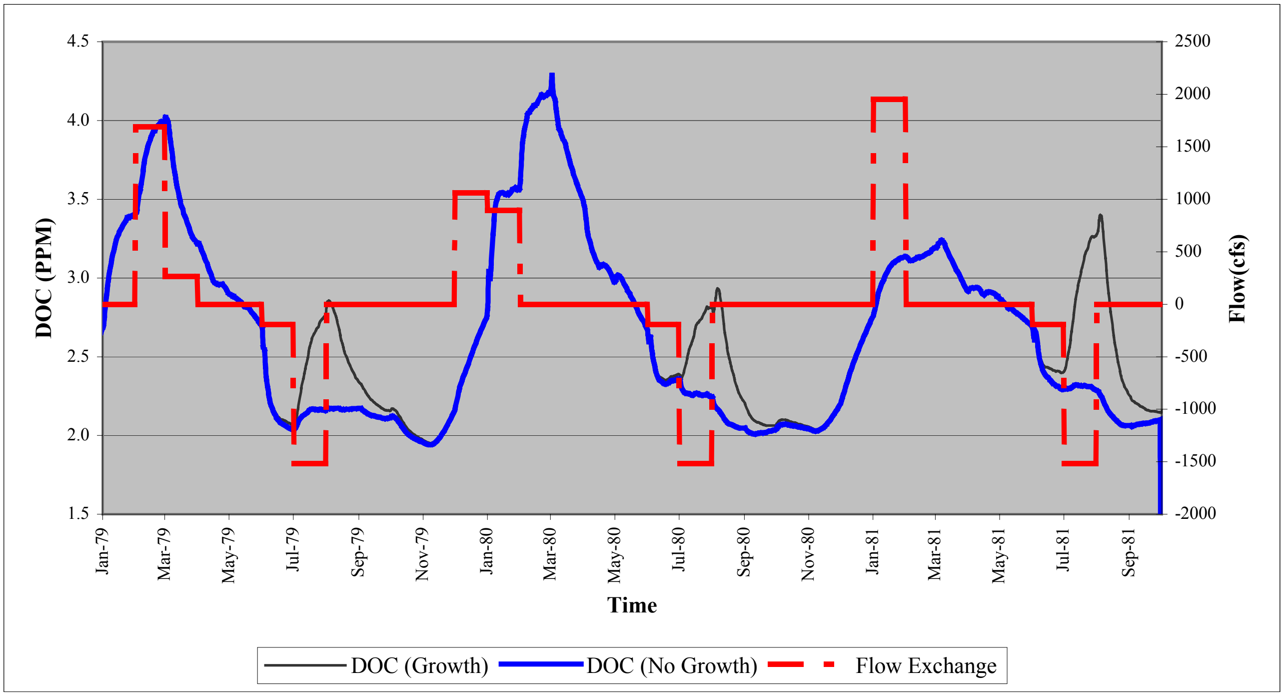


Figure 2: Time series plots of the variations in DOC concentrations at San Joaquin River near Mokelumne River junction and flow exchange at Webb Tract. The positive and negative flow values indicate filling and draining cycles, respectively.

Summary

Marvin Jung proposed a governing logistic equation for the growth of DOC in the storage reservoirs. See Equations (1) and (2). These equations were implemented dynamically into DSM2-QUAL. The algorithm requires three input variables from the user. A test case was carried out assuming two islands as storage reservoirs. The test case showed that the model was behaving as expected, and the DOC growth in the islands were consistent with Marvin Jung's algorithm. The changes in the DOC concentrations in the reservoir and channels appear to be consistent and reasonable.

References

1. Jung, Marvin (2001), "Consultants Report to the Department of Water Resources In-Delta Storage Investigations Program, Executive Summary", MWQI, California Department of Water Resources, Sacramento, CA.
2. Mierzwa, Michael (2001) "Delta Wetlands DSM2 CALSIM Studies", Presentation to In-Delta Storage Water Quality Stakeholder, October 30, Delta Modeling Section, California Department of Water Resources, Sacramento, CA.

OFFICE MEMO

TO: Paul Hutton	**DATE:** May 29, 2001
FROM: Bob Suits	**SUBJECT:** Relationships between EC, chloride, and bromide at Delta export locations

Relationships between EC and chloride and EC and bromide at Rock Slough, Los Vaqueros Intake, Clifton Court Forebay and DMC intake were developed in support of ongoing In-Delta Storage Project modeling efforts. These relationships, expressing EC as a function of either chloride or bromide are summarized in Table 1 with methodology following.

Table 1. EC, Chloride, and Bromide Relationships at Delta Export Locations

Contra Costa Canal

$EC_{\text{Old River at Rock Slough}} = 89.6 + 3.73\ (\text{Chloride}_{\text{Contra Costa Pumping Plant\#1}})$

$EC_{\text{Old River at Rock Slough}} = 118.7 + 1040.30\ (\text{Bromide}_{\text{Contra Costa Pumping Plant\#1}})$

Los Vaqueros Intake, Clifton Court Forebay, DMC Intake

$EC = 160.6 + 3.66(\text{Chloride})$

$EC = 189.2 + 1020.77\ (\text{Bromide})$

Units: EC in uS/cm, chloride in mg/l, bromide in mg/l

I. EC at Old River at Rock Slough as a function of Chloride at Contra Costa Canal Pumping Plant # 1

A regression between chloride at Contra Costa Canal Pumping Plant #1 and EC at Old River at Rock Slough was previously developed and reported in a memo from Aaron Miller to Tara Smith, dated January 2, 2001. The regression presented in that memo,

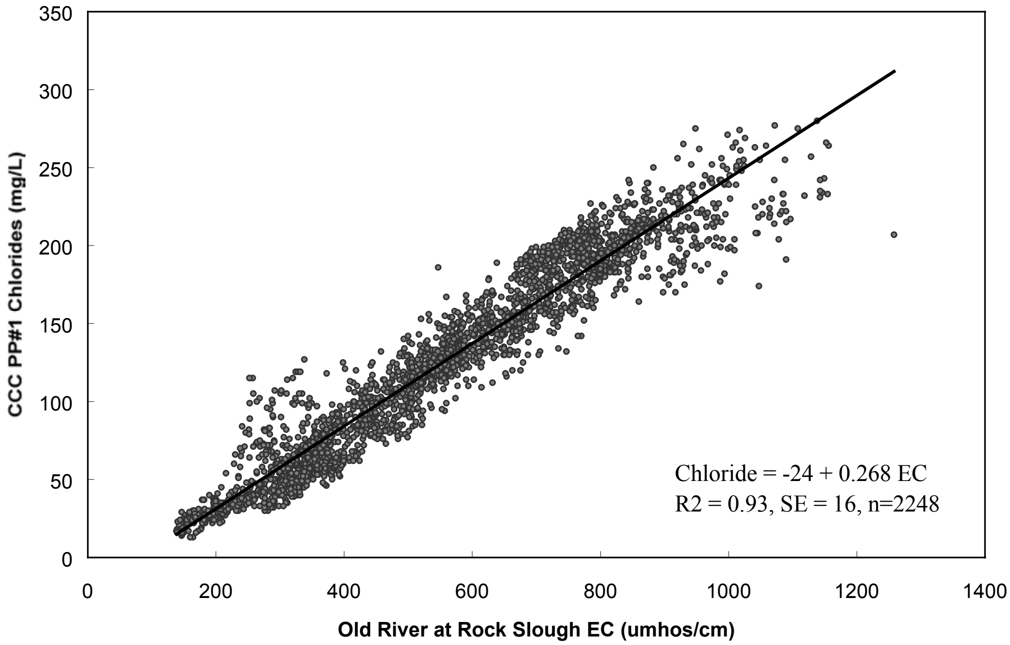
$$\text{Chloride}_{\text{Contra Costa Canal Pumping Plant \#1}} = -24 + 0.268\ (EC_{\text{Old River at Rock Slough}}) \qquad \text{(Eqn. 1)}$$

has a coefficient of determination of 0.93, a standard error of 16 mg/l, and 2,248 samples (Figure 1). Chloride and EC are in units of mg/l and uS/cm respectively. Used were EC data from Old River at Rock Slough collected by DWR's D-1485 Compliance Monitoring Program and chloride data at CCCPP#1 collected by Contra Costa Water District, all from the period of January 1967 through February 1995. To account for travel time, chloride data at CCCPP#1 were lagged 4 hours with respect to Old River at Rock Slough data before analysis was performed. Data collected during the unusual events of the San Andreas Island levee break of 1972 and the temporary barrier installations during the drought of 1976-1977 were not included in this analysis. EC and chloride concentrations were presented as daily average values.

Rewriting equation 1 in terms of EC as a function of chloride yields:

$EC_{\text{Old River at Rock Slough}} = 89.6 + 3.73\,(\text{Chloride}_{\text{Contra Costa Pumping Plant\#1}})$ (Eqn. 2)

Figure 1. Daily Average Old River at Rock Slough EC and Contra Costa Canal Intake Chloride (4 day lag)



II. EC and Chloride in Old River at Los Vaqueros Intake

EC and chloride grab sample data in or near Old River at several locations were examined to develop a relationship valid for the Los Vaqueros intake. Data collected by DWR's Municipal Water Quality Investigations Program at Old River at Highway 4, North Victoria Canal near Old River, Santa Fe - Bacon Island Cut near Old River, Rock Slough at Old River, and Old River at Bacon Island were examined along with data collected by the D1485 Water Quality Monitoring Program at Old River at Bacon Island (Figure 2). EC and chloride data from both programs usually were available from monthly or bimonthly surveys mainly from the 1990's. As shown in Figure 3, the relationship between EC and chloride at the Los Vaqueros intake site (Highway 4) is consistent with a general relationship spanning the reach from Old River at Highway 4 to the Bacon Island sampling site. The resulting regression from using all of the data is close to the regression derived from using only the data from Highway 4, and is valid over a larger range of data. The regression:

$EC = 160.6 + 3.66(\text{Chloride})$ (Eqn. 3)

has a coefficient of determination of 0.99, standard error of estimate of 35.7 uS/cm and sample size of 683. Chloride and EC are in units of mg/l and uS/cm respectively.

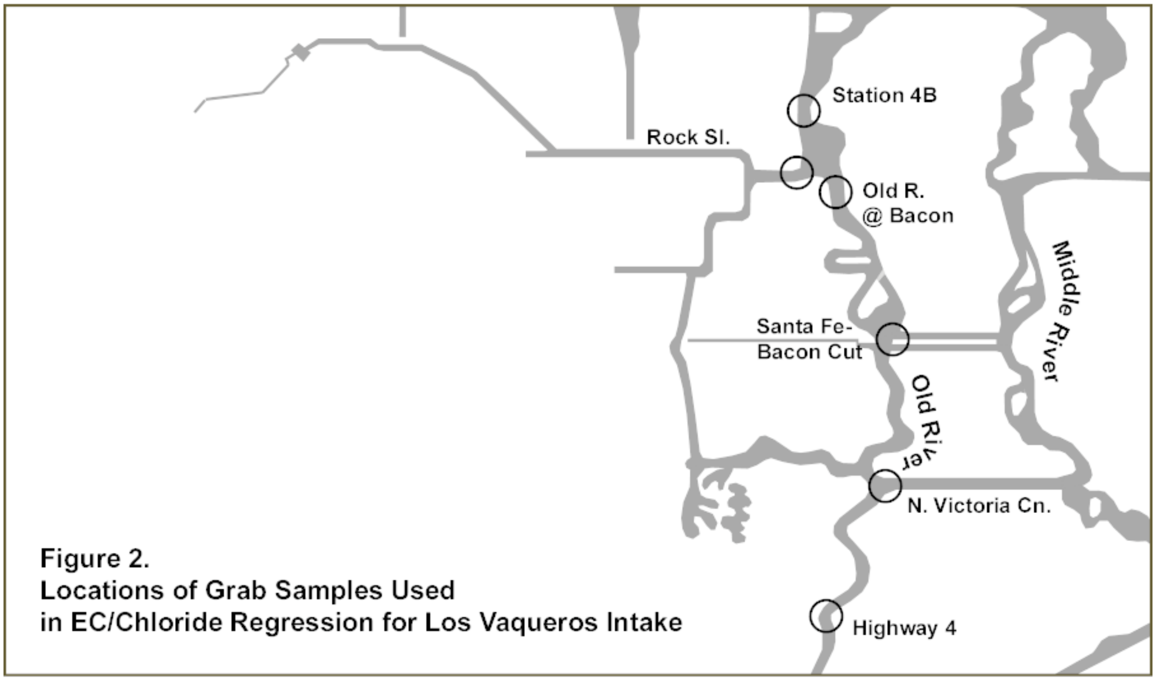
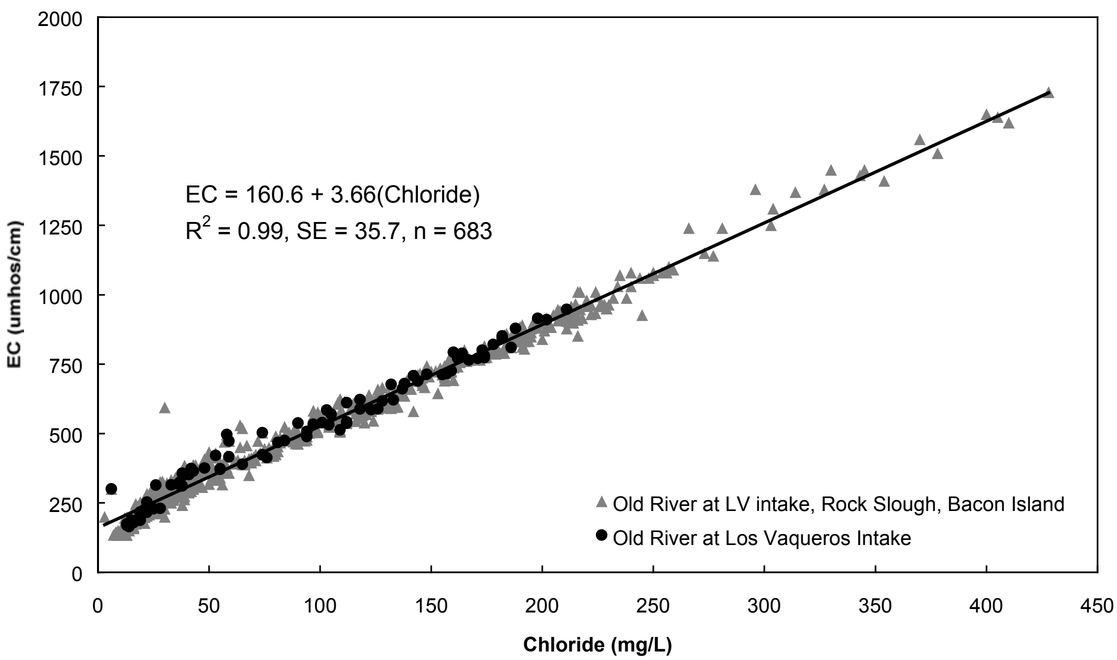


Figure 2.
Locations of Grab Samples Used
in EC/Chloride Regression for Los Vaqueros Intake

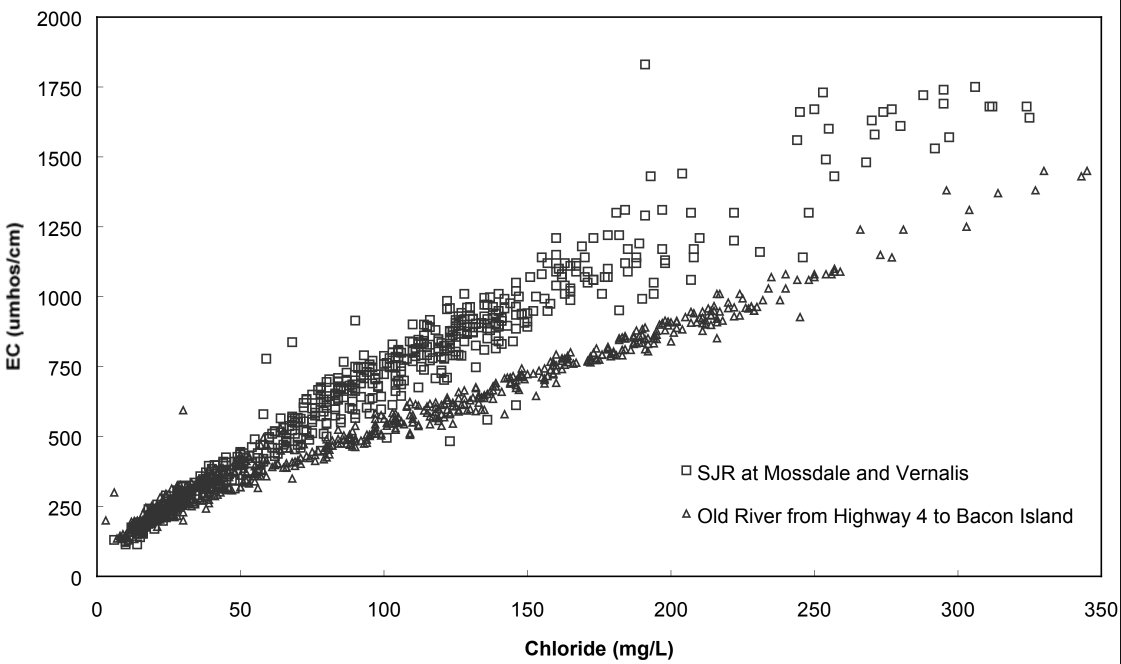
Figure 3. EC and Chloride in Old River at Los Vaqueros Intake and Nearby Locations



III. EC as a Function of Chloride at SWP and DMC Intakes

The relationship between EC and chloride in the vicinity of Clifton Court Forebay and DMC intakes in the south Delta is more complex than the one for the Los Vaqueros intake. In general, the relationship between EC and chloride in this area of the Delta depends upon whether the source of the water at the time of sampling is primarily the San Joaquin River or the Sacramento River. EC and chloride data from the San Joaquin River at Mossdale and Vernalis are plotted with data from Old River at Highway 4 to Bacon Island in Figure 4. For a given chloride level, the corresponding EC will be higher in water originating in the San Joaquin River than water from the Sacramento River. Locations along Old River from Tracy Road to North Canal, including Clifton Court Forebay and DMC intakes, may experience EC to chloride ratios indicative of either San Joaquin River water or Sacramento River water, depending upon the Delta hydraulics when the sample was taken. Figures 5 and 6 show how DMC intake and Banks Pumping Plant samples compare to the trends displayed from samples taken from San Joaquin and Old rivers.

Figure 4. EC and Chloride Old River from Highway 4 to Bacon Island and San Joaquin River at Vernalis and Mossdale



The EC-chloride relationship at Banks Pumping Plant is generally similar to that seen from the Old River samples, however some samples indicate San Joaquin River may have been a significant source. The EC-chloride relationship at DMC intake is about evenly split between the two trends, indicating that the San Joaquin River may be a more significant source of water for the DMC than for Banks Pumping Plant. These figures also show the difficulty in using a single linear regression to express the relationship between EC and chloride here. Historic San Joaquin and Sacramento River inflows, SWP and CVP delta exports, Delta outflow, and channel depletions were briefly examined to assess the possibility of predicting the EC-chloride relationship at any given time. These cursory attempts to date haven't been successful and this issue for now is left for future investigation. For the purpose of converting standards written in chloride to standards in EC at SWP and DMC intakes, it is proposed that the equation developed above for Old River at Los Vaqueros intake be used:

$$EC = 160.6 + 3.66(\text{Chloride}) \quad \text{(Eqn. 3)}$$

with EC in units of uS/cm and chloride in mg/l. When chloride is given, this equation will be effective most of the time in predicting EC at Banks Pumping Plant. It also provides conservative (lower) values of EC when converting standards from chloride to EC at both Banks Pumping Plant and DMC intake.

Figure 5. EC and Chloride at DMC Intake Compared to Old River from Hwy 4 to Bacon Is. and San Joaquin River

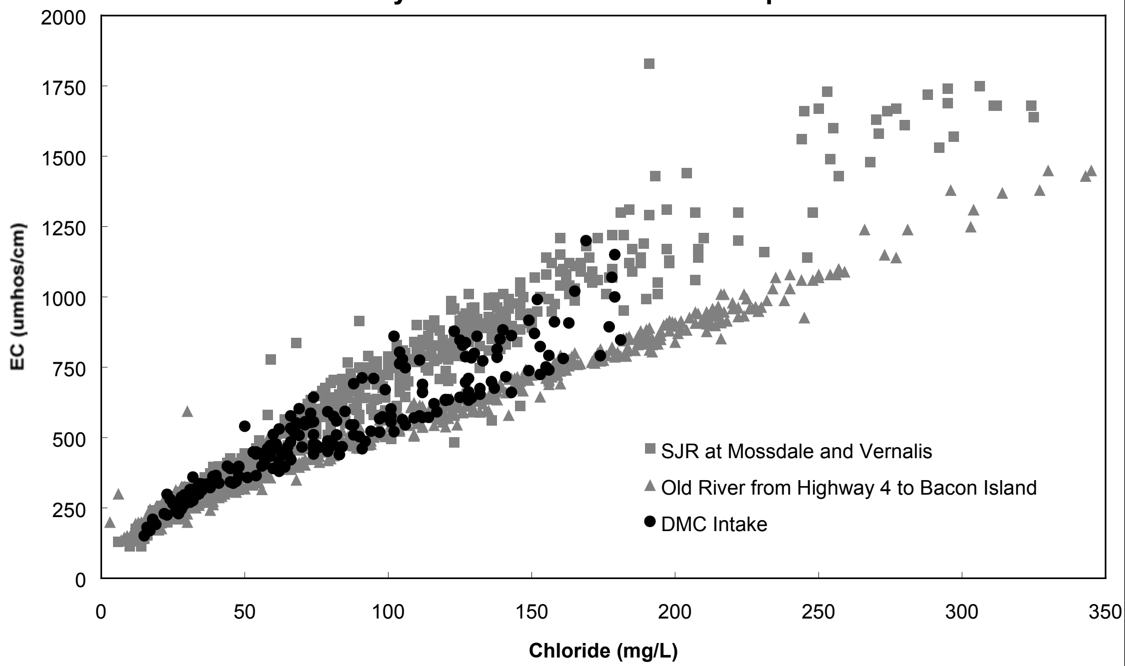
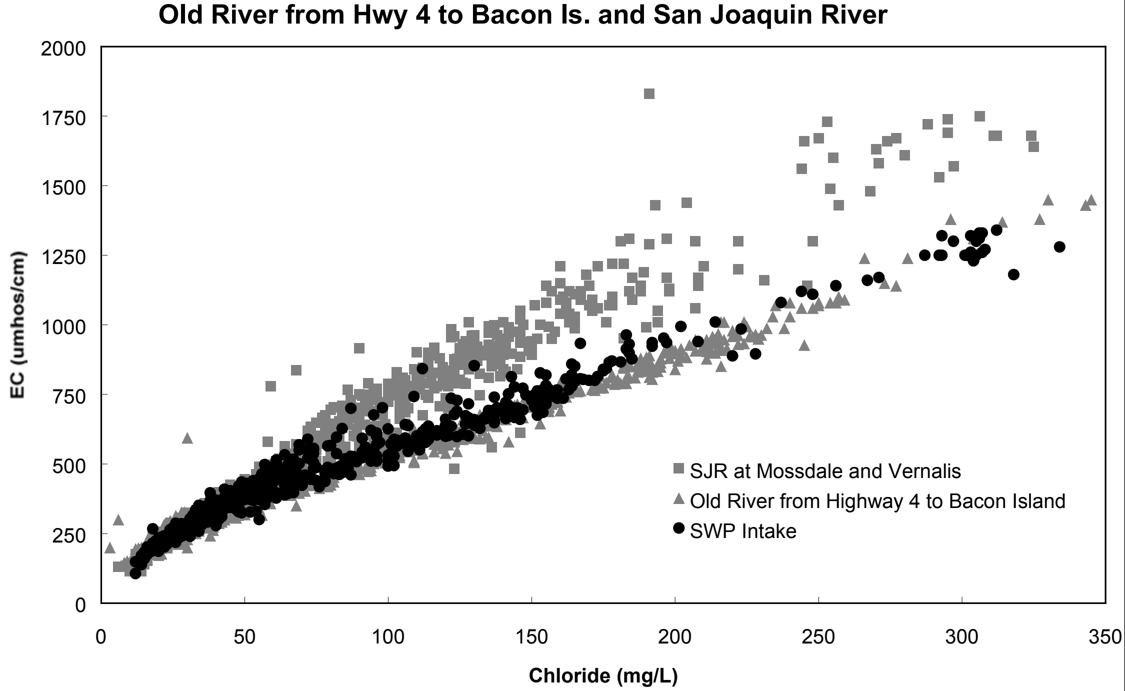


Figure 6. EC and Chloride at Banks Pumping Plant Compared to Old River from Hwy 4 to Bacon Is. and San Joaquin River



IV. Chloride as a Function of Bromide at Delta Exports

Grab samples collected by DWR's Municipal Water Quality Investigations Program and Operations and Maintenance Division were used to develop regressions between chloride and bromide at Old River at Rock Slough, Los Vaqueros intake, Clifton Court Forebay, and DMC intake. The data are mostly monthly or bimonthly samples from the 1990s and sample sites range from Old River upstream of the DMC intake to Old River downstream of Rock Slough (Figure 7). Location specific regressions were very similar, indicating that the relationship between chloride and bromide in the region is fairly uniform (Table 2). Therefore a single regression was generated from all of the data available for the sites shown in Figure 8:

$$\text{Chloride} = 7.8 + 278.9\ (\text{Bromide}) \qquad \text{(Eqn. 4)}$$

With coefficient of determination of 0.96, standard error of 10.7 mg/l, and sample size of 1,094 grab samples. Chloride and bromide are in units of mg/l.

Table 2. Chloride as a Function of Bromide in Vicinity of Delta Export Locations

Old River at Rock Slough Vicinity
Chloride = 7.8 + 281.5 (Bromide)

Old River at Rock Slough Vicinity	
Chloride = 8.5 + 281.5 (Bromide)	n = 262, SE = 10.9 mg/l, R2 = 0.94
Los Vaqueros Intake Vicinity	
Chloride = 7.9 + 281.5 (Bromide)	n = 394, SE = 9.9 mg/l, R2 = 0.95
DMC Intake Vicinity	
Chloride = 6.0 + 278.1 (Bromide)	n = 141, SE = 10.4 mg/l, R2 = 0.97
Banks Pumping Plant/Clifton Court Forebay Intake	
Chloride = 7.2 + 277.9 (Bromide)	n = 296, SE = 12.2 mg/l, R2 = 0.97

Chloride, bromide in mg/l

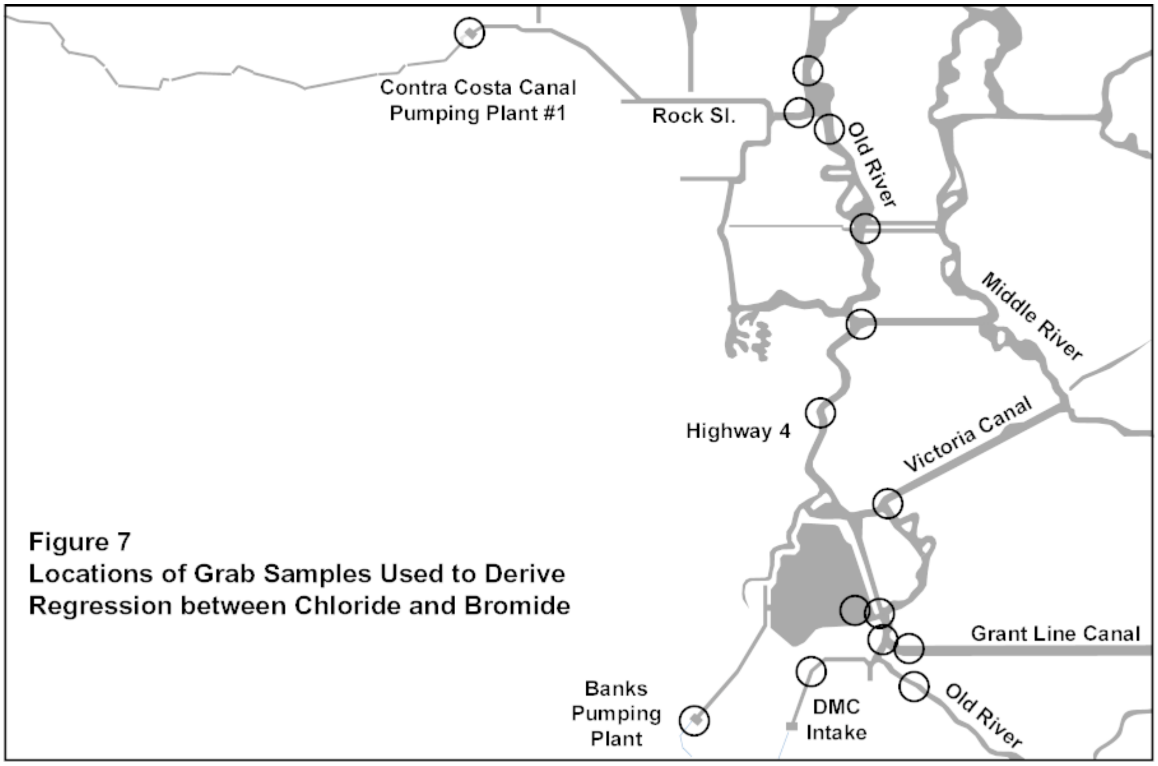
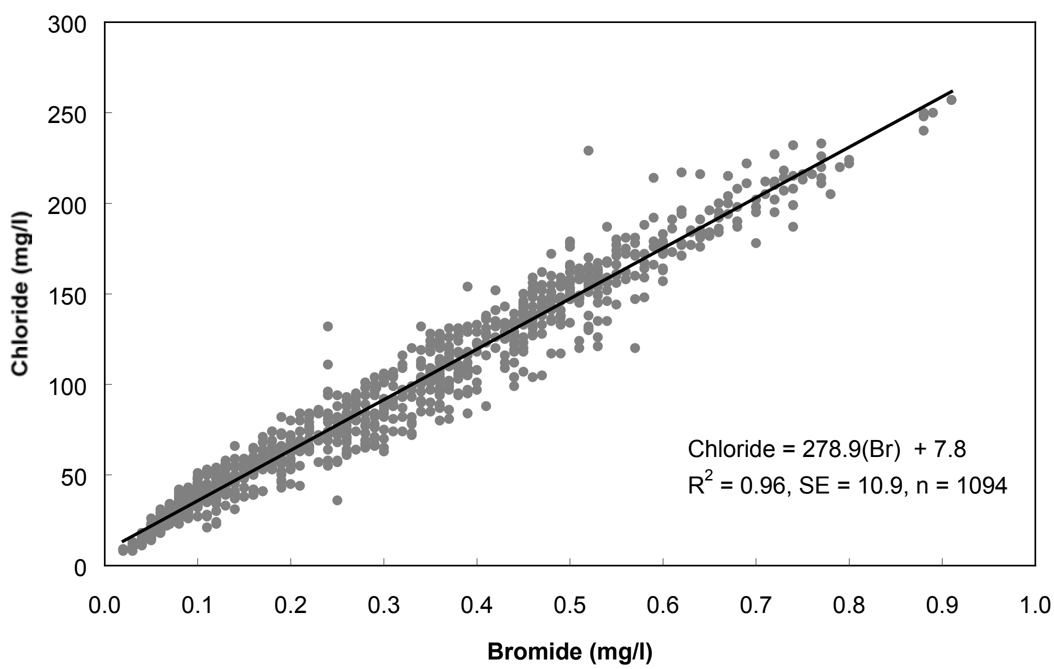


Figure 7
Locations of Grab Samples Used to Derive Regression between Chloride and Bromide

Figure 8. Chloride and Bromide in the Vicinity of Delta Exports



V. EC at Old River at Rock Slough as a Function of Bromide at Contra Costa Canal Pumping Plant #1

Equation 4 was substituted into Equation 2 to yield:

$$EC_{\text{Old River at Rock Slough}} = 118.7 + 1040.30\,(\text{Bromide}_{\text{Contra Costa Pumping Plant\#1}}) \qquad \text{(Eqn. 5)}$$

with EC in units of uS/cm and bromide in units of mg/l.

VI. EC as a Function of Bromide at Los Vaqueros Intake, Clifton Court Forebay, and DMC Intake

Equation 4 was substituted into Equation 3 to yield:

$$EC = 189.2 + 1020.77\,(\text{Bromide}) \qquad \text{(Eqn. 6)}$$

with EC in units of uS/cm and bromide in units of mg/l.

OFFICE MEMO

TO: Dr. Paul Hutton, PhD.	**DATE:** May 17, 2001
FROM: Bruce Agee	**SUBJECT:** Estimated DOC/TOC Ratios For Modeling Purposes

The MWQI program has been collecting dissolved organic carbon (DOC) and total organic carbon (TOC) data since 1986. Although DOC data is available for the entire time period, TOC was measured mostly at during the 1980's and since 1997. You asked if we could develop an estimate of TOC based on historical ratios between TOC and DOC in our data set.

Historic DOC/TOC Ratio

I reviewed the data from four regional perspectives:

1. American, Sacramento, and San Joaquin Rivers,
2. Agricultural Drain Stations,
3. Non-Agricultural Drain Stations, and
4. Selected Old and Middle River Stations

Because DWR recently changed the method of analysis of TOC from wet oxidation to combustion, I used only that data analyzed before November 1, 2000. A summary of this work is included in the attached Excel File titled TOC_DOC_Comparison.xls.

I estimated DOC/TOC ratios by two methods. In the first method, I divided the average DOC by the Average TOC for all data in the group.

The second method was initially developed for the agricultural drain data. The agricultural drain data was the most challenging because organic carbon values ranged from about 3 mg/L to 119 mg/L. Data in the other groups typically ranged from 3 mg/L to 5 mg/L. I was concerned that the high organic carbon numbers would tend to overpower the low numbers in the grand average. To deal with this, I summarized average DOC and TOC by month and by drain (i.e. up to 12 monthly averages per drain). This tended to group carbon data into narrow ranges. I then computed the average of the DOC/TOC ratios. I repeated this method for all of the regional groupings for consistency. Since DOC cannot exceed TOC, all ratios greater than 1 were rounded to 1.

Based on my calculations, the DOC/TOC ratio for all regional groupings should be 1.

Combustion Method TOC

Bryte Lab recently changed the method of analysis for TOC to the combustion method (TOCox). The reason for the change is that the wet oxidation method does not do a good job of converting particulate organic carbon into a form detected by the analyzer. While the two methods provide virtually identical results for DOC, they can differ significantly when analyzing for TOC. The greater the amount of particulate organic carbon present, the greater the difference between the results by the two methods.

In an attempt to show how future DOC/TOC estimates may change, I estimated DOC/TOCox for some of the MWQI data and have included these estimates in the spreadsheet. Since the combustion method TOC was only introduced in February, 2000, there are only about 5 months of data to evaluate.

Generally, DOC/TOCox ratios range from 0.9 to 0.26. The six month average for the American, Sacramento and San Joaquin Rivers is about 0.6.

I did a similar analysis using Barker Slough at the North Bay Aqueduct data. This location was chosen because it is the most turbid site we currently monitor. I used data collected since February, 2000 because the TOC oxidation method was improved and did yield improved results from February on. Data collected from November to present was by the combustion method. The monthly average DOC/TOCox ratios at Barker North Bay range from about 0.6 to about 1.0. These results should not be used for input into the model, only to give a feel for how future refinements to the model might look.

<u>Recommendations</u>

I recommend that the MWQI program continue collecting both DOC and TOC measures. They should also conduct a study of active agricultural drains to determine a reasonable estimate of DOC/TOCox. This study should cover at least 12 calendar months and include at least one representative drain from the high, medium, and low organic carbon producing regions in the Delta.

If you have any questions about this work, please contact me at (916) 327-1677.

-- Bruce

OFFICE MEMO

TO: Paul Hutton	**DATE:** November 19, 2001
FROM: Bob Suits	**SUBJECT:** Boundary DOC and UVA for DSM2 Planning Studies

Dissolved organic carbon (DOC) and ultraviolet absorbance (UVA) have been developed for the Sacramento River at Greens Landing, the San Joaquin River at Vernalis, and the Mokelumne River at I-5 for the 1975 - 1991 planning simulation period. This memo presents these data and details the methodology used.

General Methodology

The averaged observed DOC from June through October DOC (approximately from 1987 through 1998) was assigned as monthly DOC for the same months over the planning period. In order to generate DOC for the remaining months, relationships between observed DOC and flow were established and then applied to the historic flows over the planning period.

Relationships between DOC and flow were found by first partitioning observed DOC into 3 or 4 categories according to the ratio of observed DOC to historic flow. The categories were presented as containing data exhibiting "low", "moderate", or "high" DOC response to flow. Regressions were then found between DOC and flow for each category of data. Historic patterns of DOC/Flow values were then examined to determine the conditions under which low, moderate, or high DOC response to flow occurred in the past. General trends in the historic data were used to assign each month in the planning period with low, moderate, or high DOC/Flow values. Each month then was assigned a constant DOC (for June through October) or a regression was applied to the flow to obtain DOC. Finally, any generated DOC was limited to falling within minimum and maximum observed DOC at that location.

UVA over the planning period was generated at the three sites by applying regressions between historic UVA and DOC to the generated DOC.

Historic DOC and UVA was available from once or twice-per-month grab samples collected over the approximate period of 1987 through 1998 by MWQI. DOC and UVA in the American River were used as a surrogate for the Mokelumne River. Multiple values of DOC or UVA in any given month were averaged together to yield one value per month. Monthly average flows in the Sacramento, San Joaquin, and American rivers were determined from DAYFLOW.

Greens Landing DOC and UVA

Figure 1 shows historic DOC and flow in the Sacramento River at Greens Landing. DOC from June through October was averaged to yield a single value of 1.81 mg/L to approximate monthly DOC from June through October for the planning period (Figure 2). DOC in other months exhibited a pattern of high values associated with the first large flows of the fall/winter and low values after sustained high flows. Figure 3 and Table 1 show that, after excluding the June-October data, partitioning DOC according to DOC/flow ratio, yielded reasonable regressions between DOC and flow.

Historic flows at Greens Landing were then described as being associated with "low," "intermediate," or "high" DOC response (Figure 4). Observed patterns of DOC response to flow were applied to the planning period by considering current and preceding flows. This allowed each monthly flow during the planning period to be associated with either 1.81 mg/L DOC (June - October), or with one of three regressions with DOC (Figure 5).

After assigning a DOC of 1.81 mg/L to each month from June through October, appropriate regressions were applied to average flows from other months to generate monthly DOC. DOC derived from the regressions was limited to between 1.5 and 5.5 mg/L, the minimum and maximum values seen in the observed data. Figure 6 compares the historic DOC to the DOC generated by this method. Figure 7 and Table 2 show the resulting DOC over the planning period. Peak DOC occurred periodically when flow first increased in the fall or winter after several months of relatively low flow. The average DOC generated at Greens Landing by this process over the planning period was similar to the average observed DOC (Figure 8).

UVA at Greens Landing was generated by applying a regression based on observed DOC and UVA at Greens Landing (Figure 9) to the generated DOC (Table 2).

$$UVA = 0.039DOC - 0.03, \quad R2 = 0.8$$

Where UVA is in units of Abs/cm and DOC is in mg/L.

Average generated UVA at Greens Landing over the planning period was consistent with the average observed UVA at Greens Landing (Figure 10).

Figure 1. Observed DOC and Flow at Greens Landing

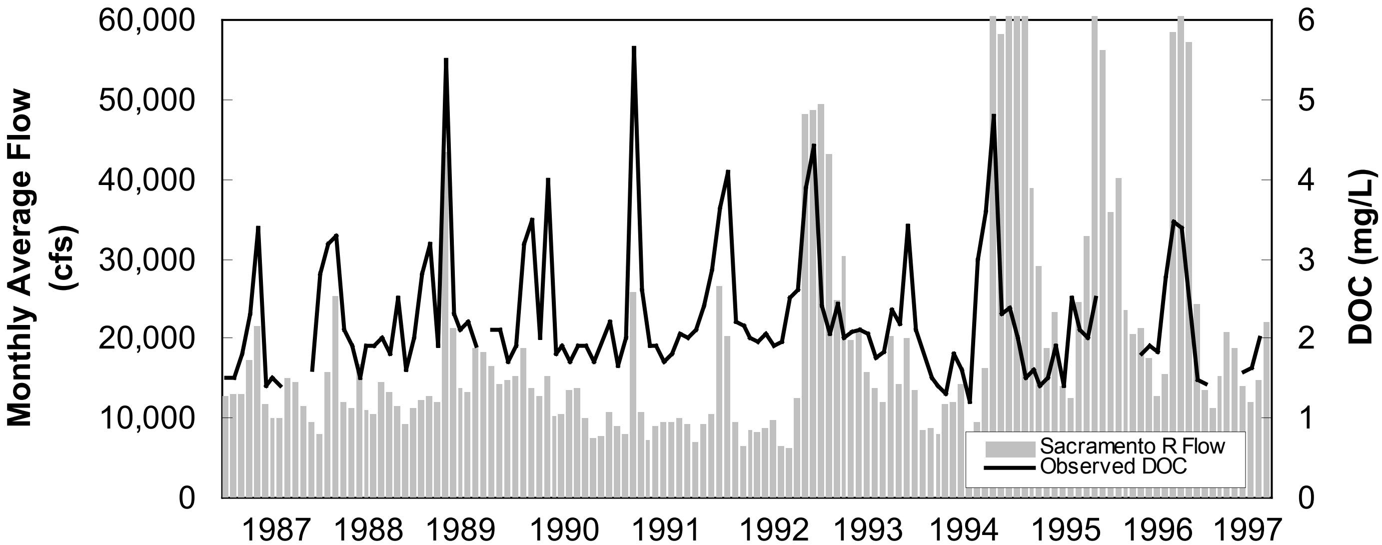


Figure 2. Observed DOC at Greens Landing, 1987 - 1997
(grouped by month)

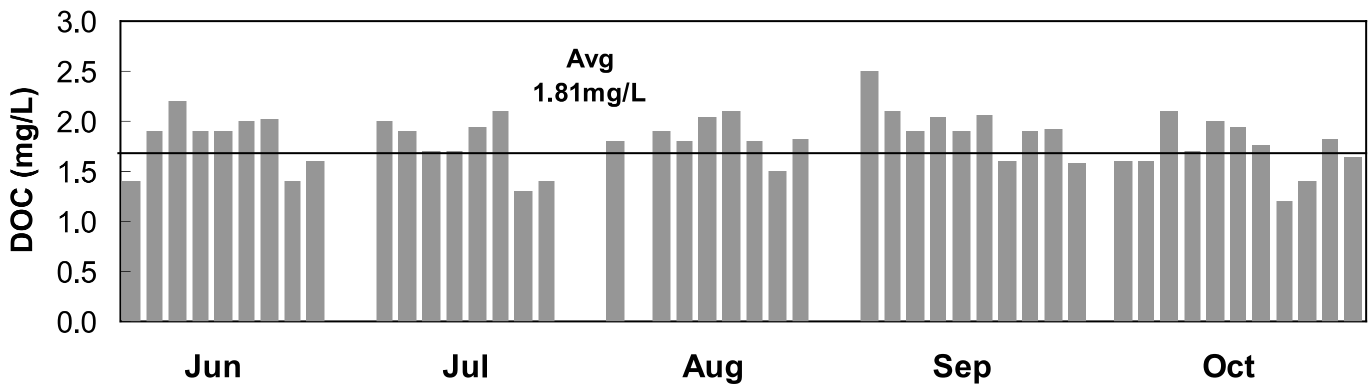


Table 1. Classification of DOC Response to Flow at Greens Landing

DOC Response to Flow	Criteria	Reqression Equation	R2
Low	7.5E-05 > DOC/FLOW	DOC = 2.0E-05(FLOW) + 1.8	0.3
Moderate	20E-05 > DOC/FLOW > 7.5E-05	DOC = 7.0E-05(FLOW) + 1.0	0.8
High	DOC/FLOW > 20E-05	DOC = 17.5E-05(FLOW) + 0.8	0.9

DOC: monthly dissolved organic carbon (mg/L)
FLOW: monthly average flow in Sacramento River at Sacramento (cfs)

Figure 3. Observed DOC at Greens Landing Grouped by Response to Flow
(June - October Values Removed)

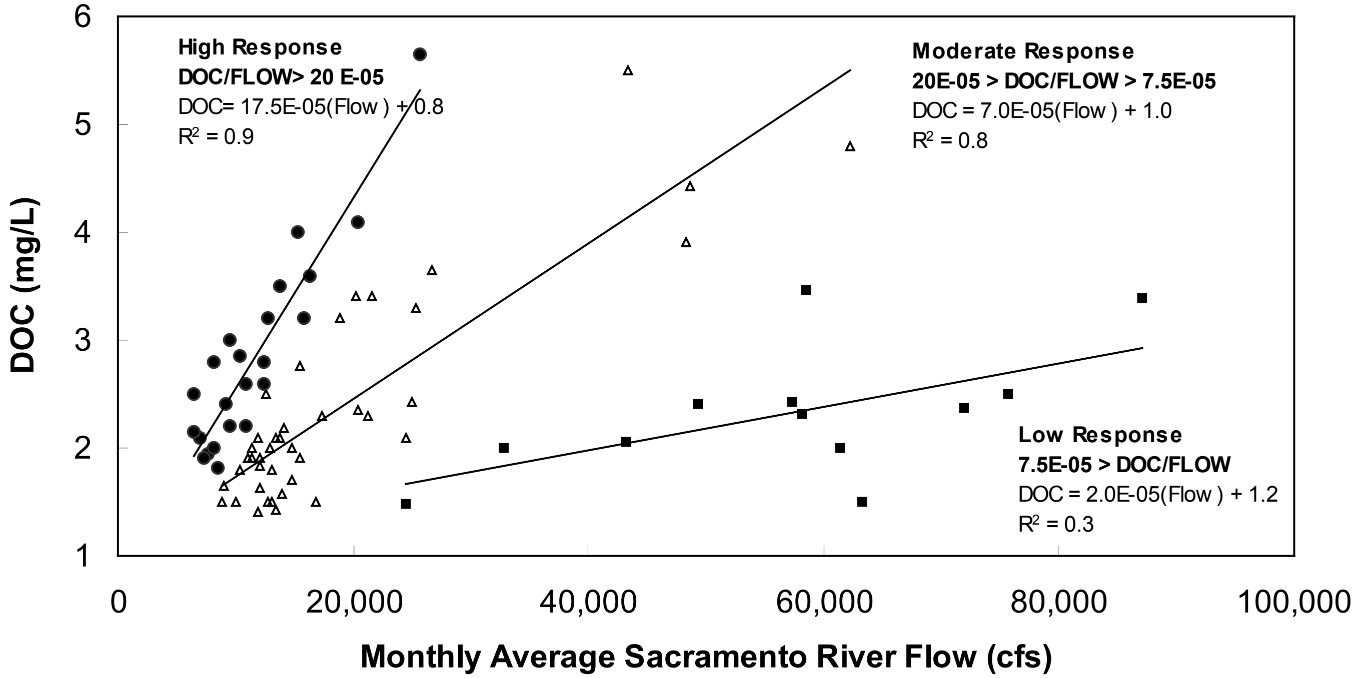


Figure 4. Observed DOC and Response to Flow at Greens Landing

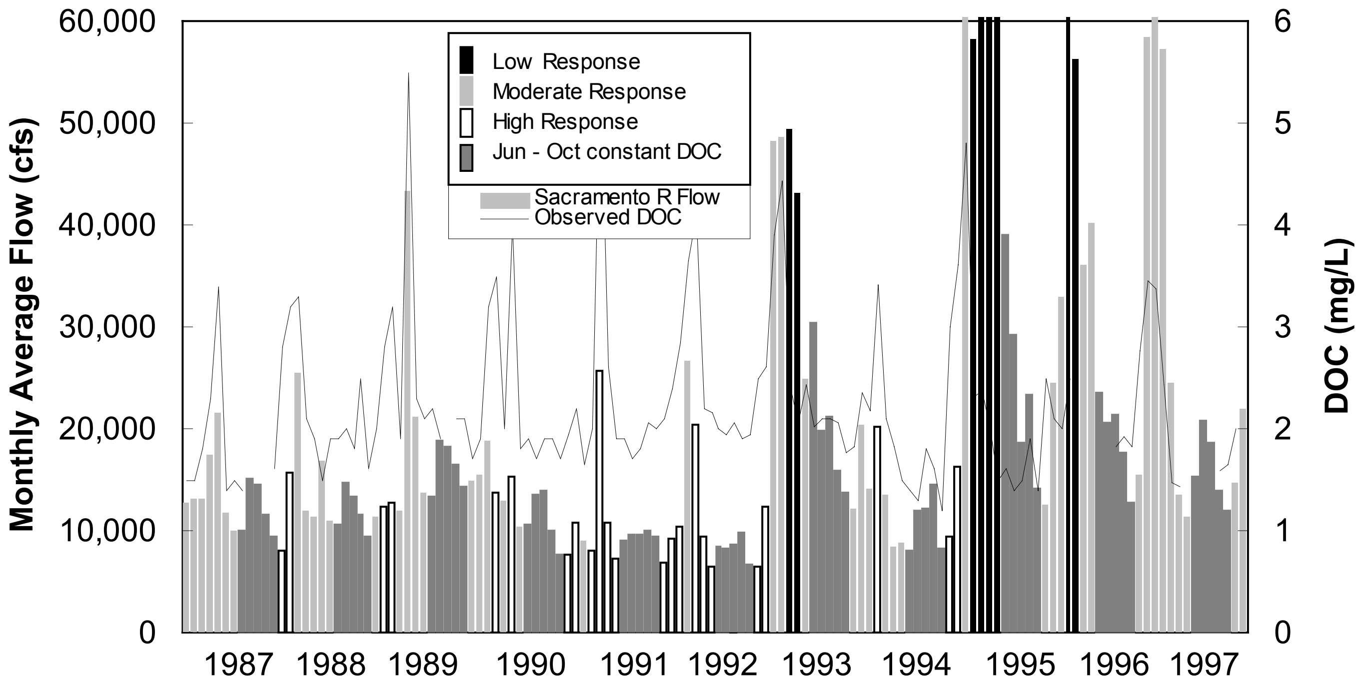


Figure 5. Assignment of DOC/Flow Relationship at Greens Landing for Planning Period

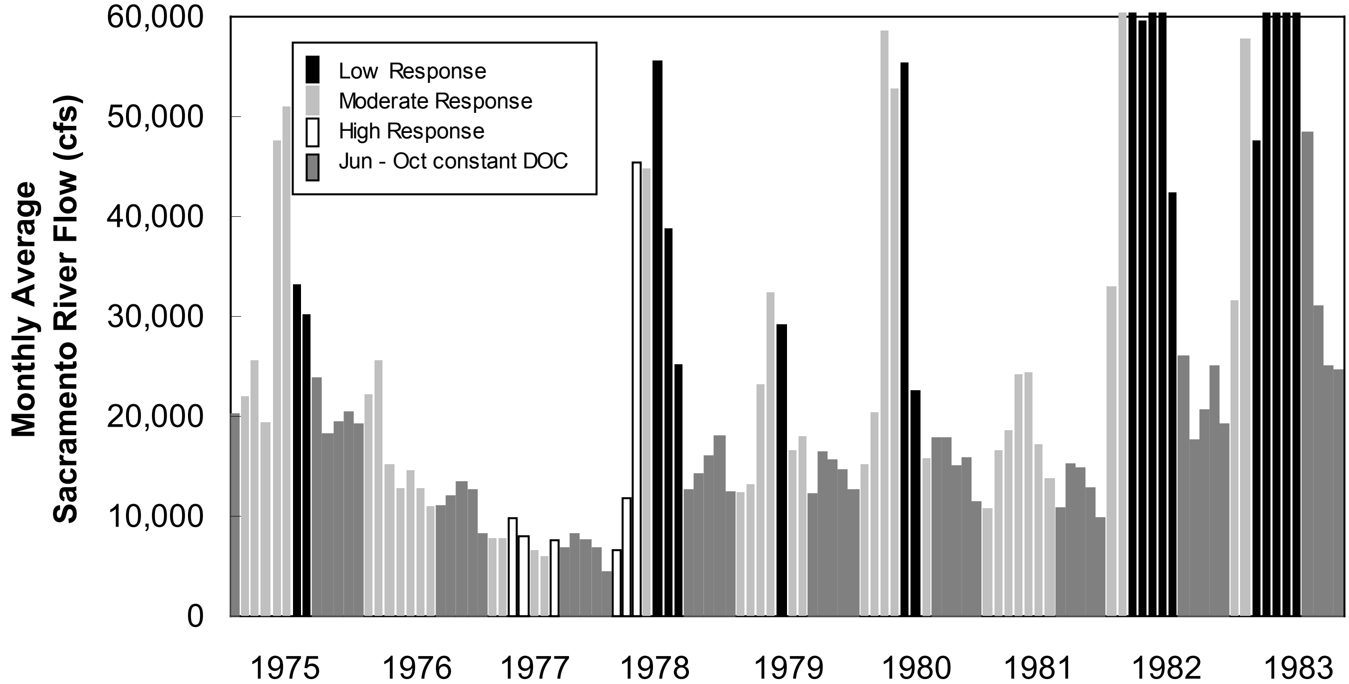


Figure 5. Assignment of DOC/Flow Relationship at Greens Landing for Planning Period

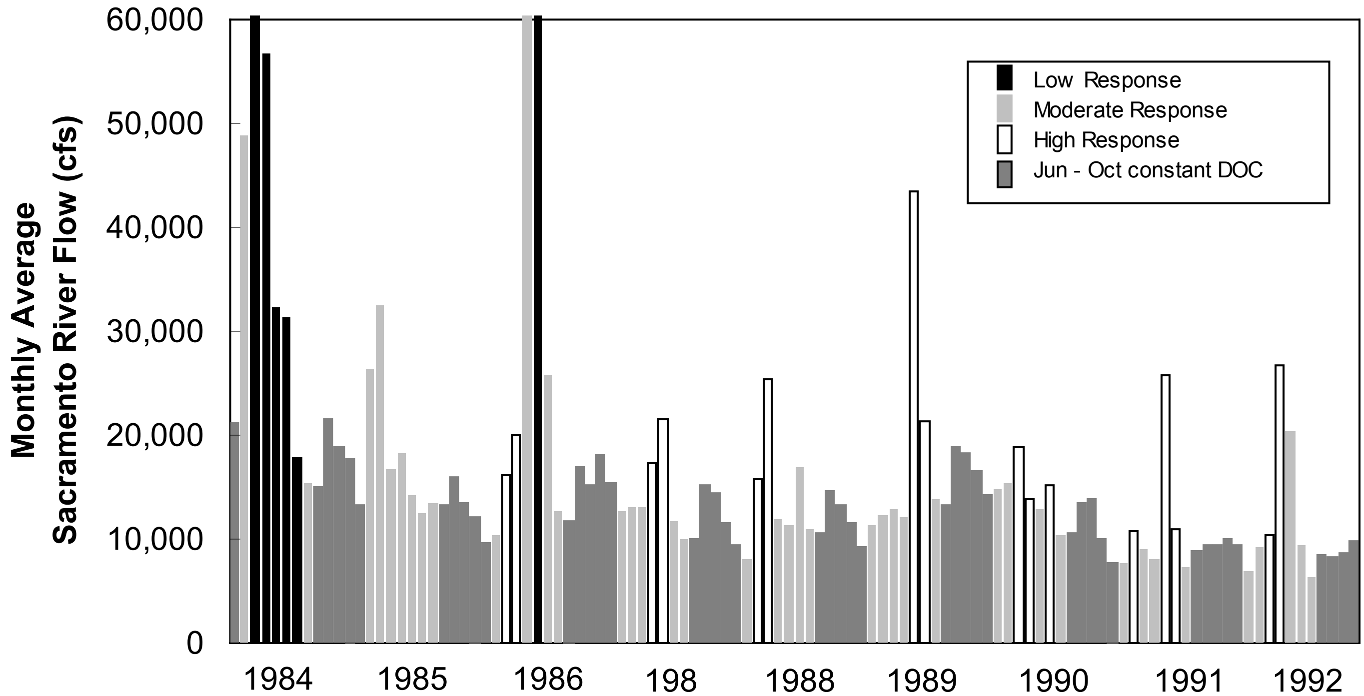


Figure 6. Observed and Generated DOC at Greens Landing

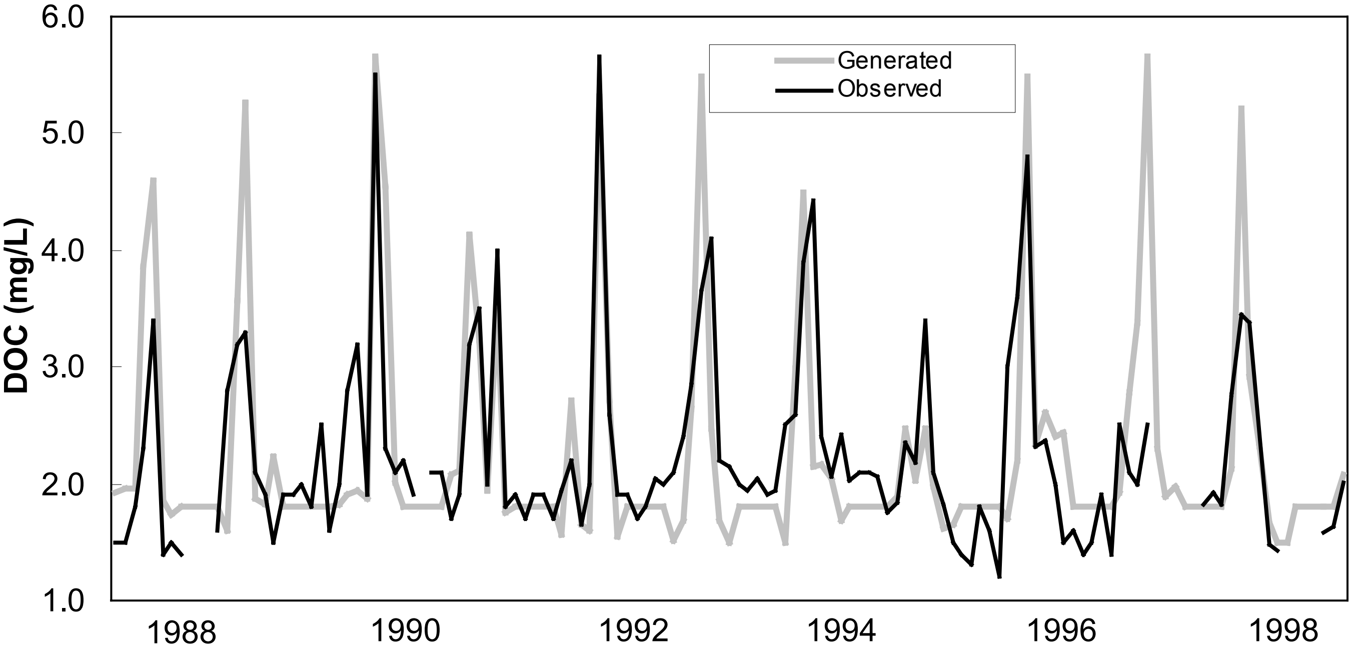


Figure 7. Generated DOC at Greens Landing

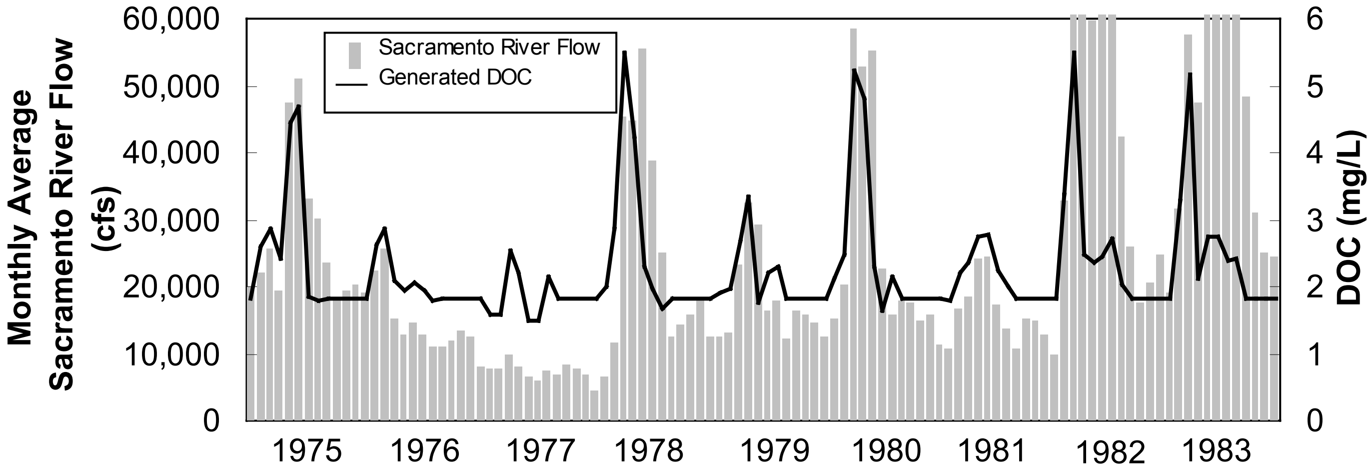


Figure 7. Generated DOC at Greens Landing

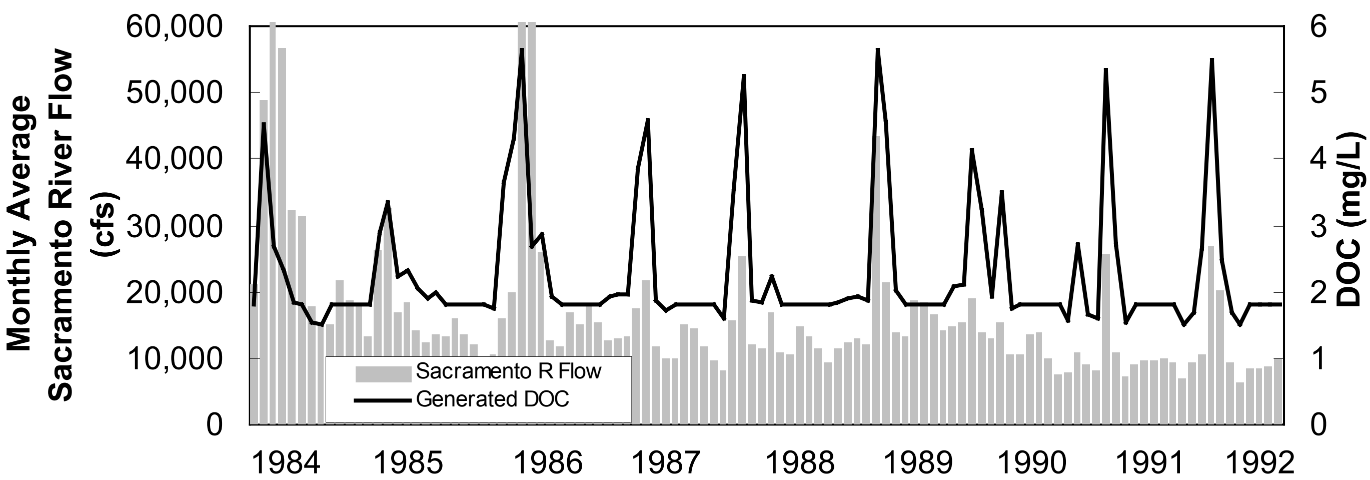


Table 2. Generated Monthly DOC at Greens Landing (values in mg/L)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975	1.81	2.60	2.86	2.41	4.43	4.68	1.84	1.78	1.81	1.81	1.81	1.81
1976	1.81	2.61	2.85	2.10	1.93	2.06	1.93	1.80	1.81	1.81	1.81	1.81
1977	1.81	1.58	1.57	2.53	2.22	1.50	1.50	2.15	1.81	1.81	1.81	1.81
1978	1.81	1.99	2.87	5.50	4.23	2.29	1.96	1.68	1.81	1.81	1.81	1.81
1979	1.81	1.91	1.96	2.68	3.35	1.76	2.20	2.31	1.81	1.81	1.81	1.81
1980	1.81	2.11	2.47	5.23	4.82	2.28	1.63	2.16	1.81	1.81	1.81	1.81
1981	1.81	1.80	2.21	2.34	2.76	2.78	2.25	2.00	1.81	1.81	1.81	1.81
1982	1.81	3.38	5.50	2.47	2.37	2.43	2.71	2.03	1.81	1.81	1.81	1.81
1983	1.81	3.28	5.17	2.13	2.76	2.74	2.39	2.42	1.81	1.81	1.81	1.81
1984	1.81	4.53	2.69	2.31	1.83	1.81	1.54	1.50	1.81	1.81	1.81	1.81
1985	1.81	2.90	3.36	2.22	2.33	2.04	1.91	1.98	1.81	1.81	1.81	1.81
1986	1.81	1.76	3.64	4.31	5.65	2.68	2.87	1.93	1.81	1.81	1.81	1.81
1987	1.81	1.92	1.96	1.96	3.86	4.59	1.86	1.73	1.81	1.81	1.81	1.81
1988	1.81	1.60	3.57	5.26	1.87	1.83	2.23	1.80	1.81	1.81	1.81	1.81
1989	1.81	1.83	1.90	1.94	1.88	5.65	4.54	2.01	1.81	1.81	1.81	1.81
1990	1.81	2.08	2.12	4.13	3.23	1.94	3.49	1.76	1.81	1.81	1.81	1.81
1991	1.81	1.57	2.71	1.66	1.60	5.32	2.72	1.54	1.81	1.81	1.81	1.81
Avg	1.81	2.32	2.91	3.01	3.01	2.85	2.33	1.92	1.81	1.81	1.81	1.81

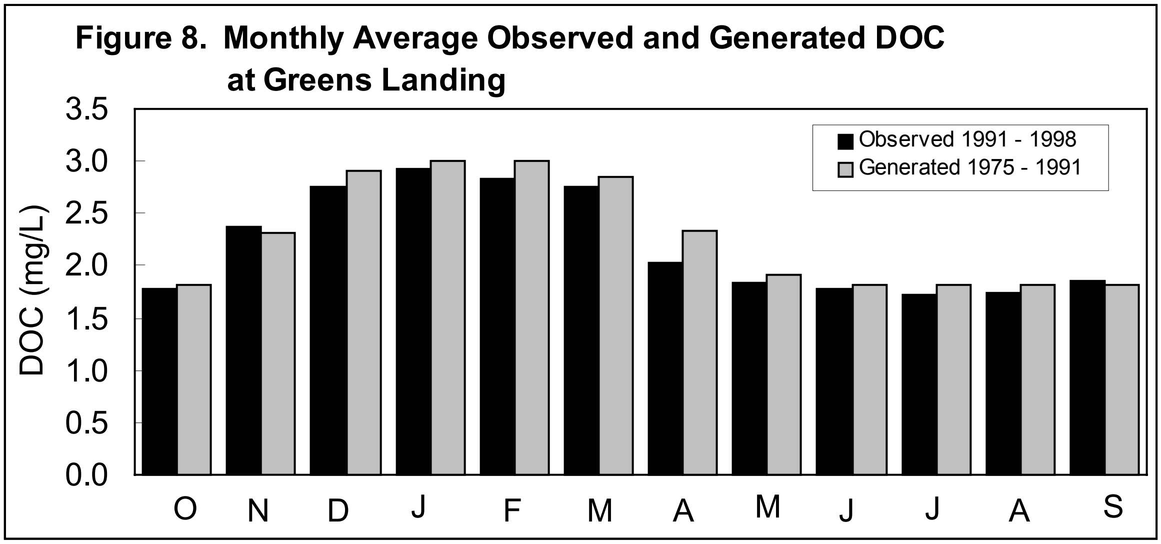


Figure 8. Monthly Average Observed and Generated DOC
at Greens Landing
DOC (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Observed 1991 - 1998
Generated 1975 - 1991
O
N
D
J
F
M
A
M
J
J
A
S

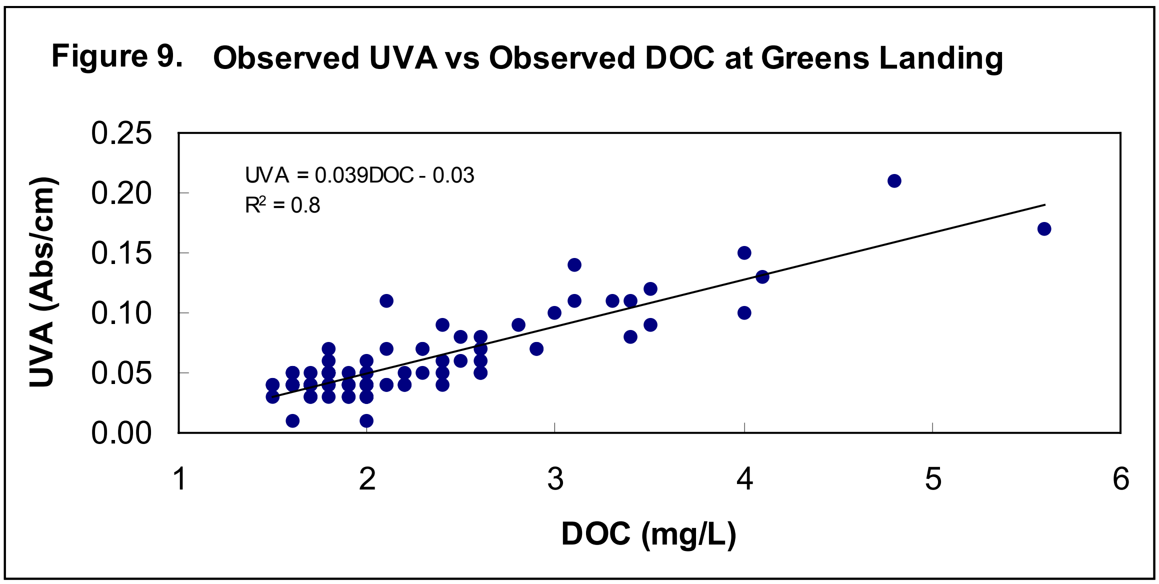
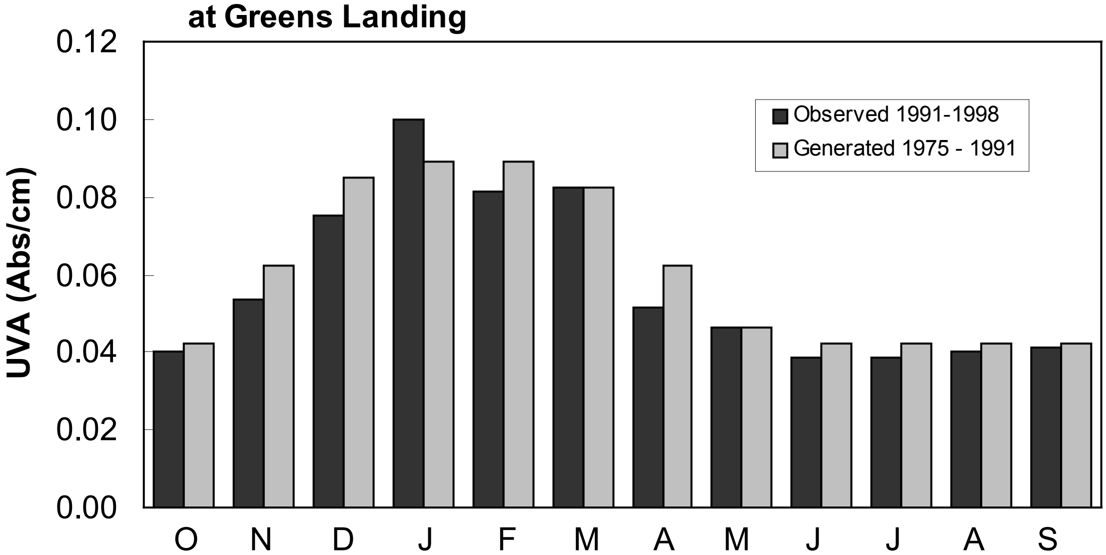


Figure 9. Observed UVA vs Observed DOC at Greens Landing
UVA (Abs/cm)
0.25
0.20
0.15
0.10
0.05
0.00
UVA = 0.039DOC - 0.03
R2 = 0.8
1
2
3
4
5
6
DOC (mg/L)

Table 3. Generated Monthly UVA at Greens Landing (values in Abs/cm)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975	0.04	0.07	0.08	0.07	0.14	0.15	0.04	0.04	0.04	0.04	0.04	0.04
1976	0.04	0.07	0.08	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04
1977	0.04	0.03	0.03	0.07	0.06	0.03	0.03	0.06	0.04	0.04	0.04	0.04
1978	0.04	0.05	0.08	0.19	0.14	0.06	0.05	0.04	0.04	0.04	0.04	0.04
1979	0.04	0.05	0.05	0.08	0.10	0.04	0.06	0.06	0.04	0.04	0.04	0.04
1980	0.04	0.05	0.07	0.18	0.16	0.06	0.04	0.06	0.04	0.04	0.04	0.04
1981	0.04	0.04	0.06	0.06	0.08	0.08	0.06	0.05	0.04	0.04	0.04	0.04
1982	0.04	0.10	0.19	0.07	0.06	0.07	0.08	0.05	0.04	0.04	0.04	0.04
1983	0.04	0.10	0.17	0.05	0.08	0.08	0.06	0.07	0.04	0.04	0.04	0.04
1984	0.04	0.15	0.08	0.06	0.04	0.04	0.03	0.03	0.04	0.04	0.04	0.04
1985	0.04	0.08	0.10	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04
1986	0.04	0.04	0.11	0.14	0.19	0.08	0.08	0.05	0.04	0.04	0.04	0.04
1987	0.04	0.05	0.05	0.05	0.12	0.15	0.04	0.04	0.04	0.04	0.04	0.04
1988	0.04	0.03	0.11	0.18	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.04
1989	0.04	0.04	0.05	0.05	0.04	0.19	0.15	0.05	0.04	0.04	0.04	0.04
1990	0.04	0.05	0.05	0.13	0.10	0.05	0.11	0.04	0.04	0.04	0.04	0.04
1991	0.04	0.03	0.08	0.04	0.03	0.18	0.08	0.03	0.04	0.04	0.04	0.04
Avg	0.04	0.06	0.08	0.09	0.09	0.08	0.06	0.05	0.04	0.04	0.04	0.04

Figure 10. Monthly Average Observed and Generated UVA at Greens Landing



Vernalis DOC and UVA

The method of generating DOC and UVA at Vernalis was similar to that described for Greens Landing. Figure 11 shows historic DOC and flow in the San Joaquin River at Vernalis. DOC from Mossdale was used if available during times when Vernalis data was missing. Average observed DOC from June through October, 3.83 mg/L, approximated monthly DOC over this interval for the planning period (Figure 12). DOC from other months again exhibited a pattern of high values associated with the first large flows of the fall/winter and low values after sustained high flows. The Vernalis/Mossdale DOC was partitioned according to DOC / Flow values into four classifications, labeled "low", moderate-low", "moderate-high", or "high" DOC response to flow. Figure 13 and Table 4 show that, after excluding the June-October data, reasonable regressions could be found between DOC and flow.

Historic DOC was then associated with "low," "low-intermediate," "high-intermediate", or "high" response to flow (Figure 14). The "high" DOC response to flow tended to be associated with the first significant flow after many months of low flow. Categories of DOC response to flow displayed in Figure 14 were assigned to the planning period by considering similar patterns in flow. This allowed each monthly flow during the planning period to be associated with either 3.83 mg/L DOC (June - October), or with one of four regressions with DOC (Figure 15).

After assigning a DOC of 3.83 mg/L to each month from June though October, regressions were applied to average flows from other months to generate DOC. DOC derived from the regressions was limited to between 2.4 and 11.4 mg/L, the minimum and maximum values seen in the observed data. Figure 17 compares the historic Vernalis/Mossdale DOC to the DOC generated by this method. Figure 18 and Table 2 show the resulting generated DOC over the planning period. The average DOC generated at Vernalis by this process over the planning period was similar to the average observed DOC (Figure 19).

UVA at Vernalis was generated by applying a regression based on observed DOC and UVA at Vernalis (Figure 20) to the generated DOC (Table 3):

$$UVA = 0.037DOC - 0.035, \quad R2 = 0.9$$

Average generated UVA at Vernalis over the planning period was consistent with the average observed UVA at Vernalis (Figure 22).

Figure 11. Observed DOC and Flow at Vernalis

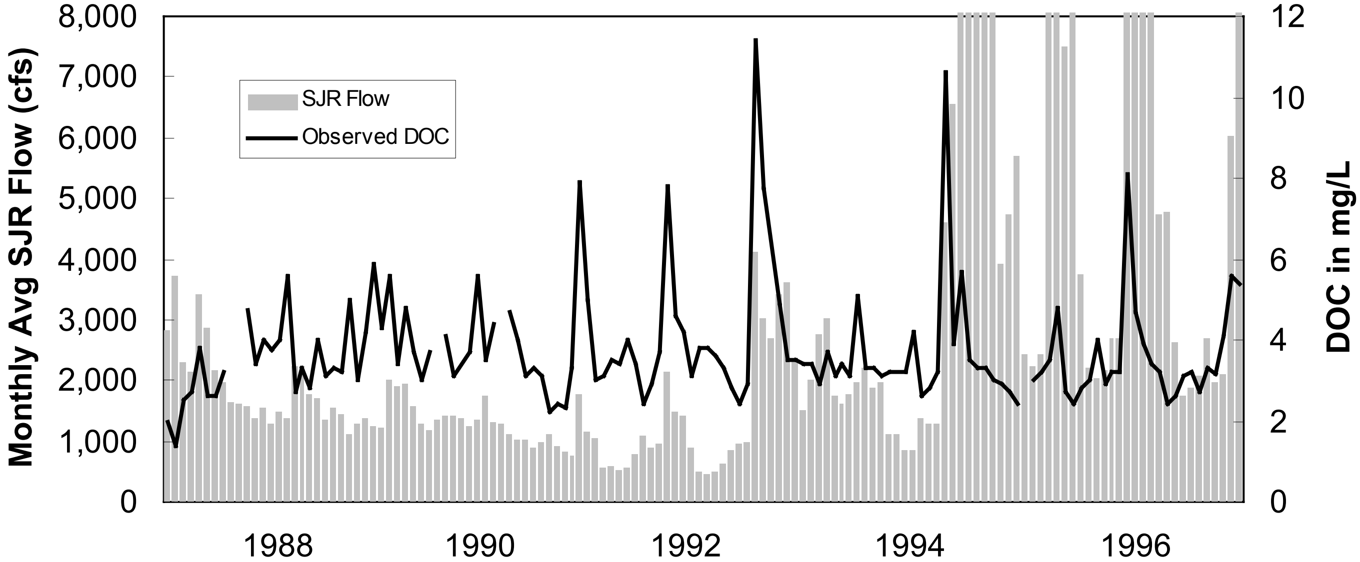


Figure 12. Observed DOC at Vernalis, 1987 - 1997
(grouped by month)

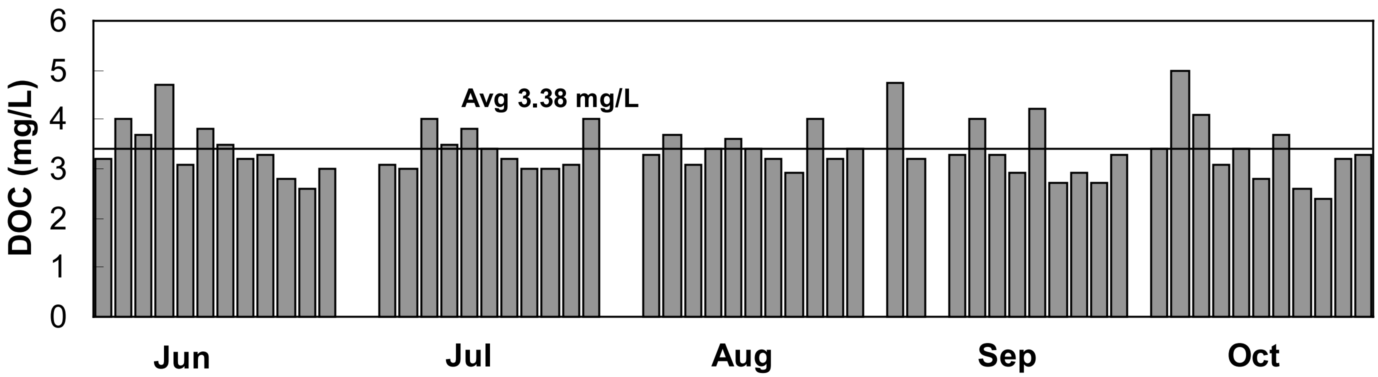


Figure 13. Observed DOC and Flow at Vernalis

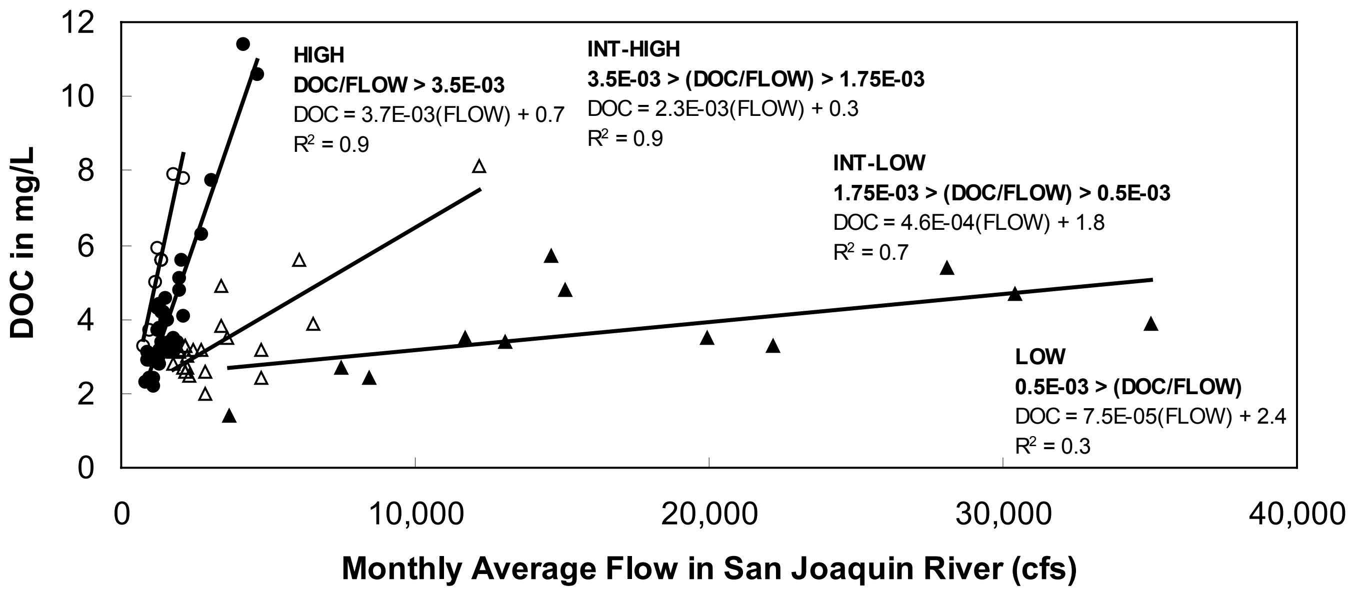


Table 4. Classification of DOC Response to Flow at Vernalis

DOC Response to Flow	Criteria	Reqression Equation	R2
Low	0.5E-03 > DOC/FLOW	DOC = 7.5E-05(FLOW) + 2.4	0.3
Moderate-Low	1.75E-03 > DOC/FLOW > 0.5E-03	DOC = 4.6E-04(FLOW) + 1.8	0.7
Moderate-High	20E-03 > DOC/FLOW > 1.75E-03	DOC = 2.3E-03(FLOW) + 0.3	0.9
High	DOC/FLOW > 20 E-03	DOC = 3.7E-03(FLOW) + 0.7	0.9

DOC: monthly dissolved organic carbon (mg/L)

FLOW: monthly average flow in San Joaquin River at Vernalis (cfs)

Figure 14. Historic SJR Flow at Vernalis Categorized by DOC Response to Flow

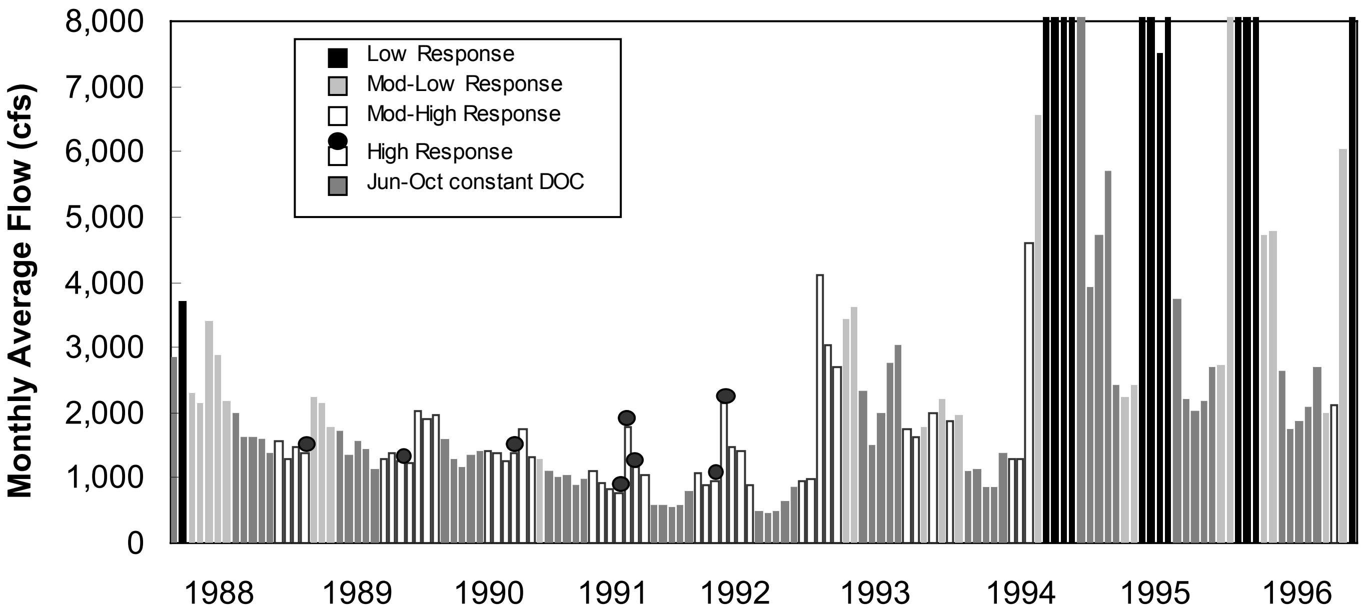


Figure 15. Assignment of DOC/Flow Relationship at Vernalis for Planning Period

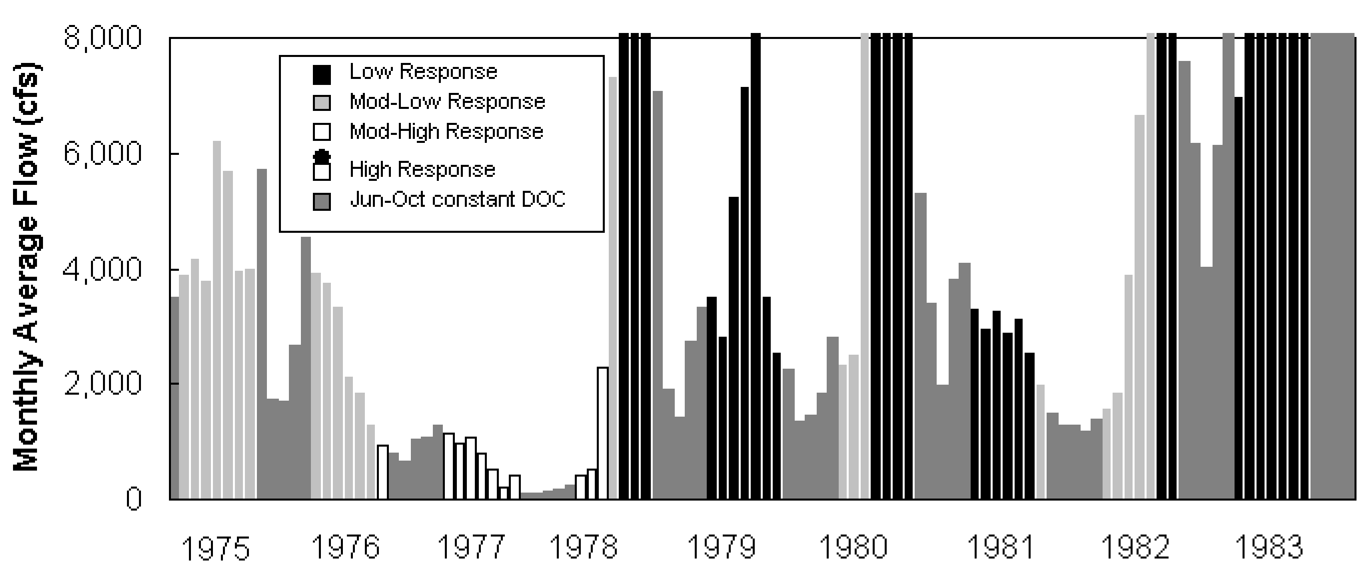


Figure 15. Assignment of DOC/Flow Relationship at Vernalis for Planning Period

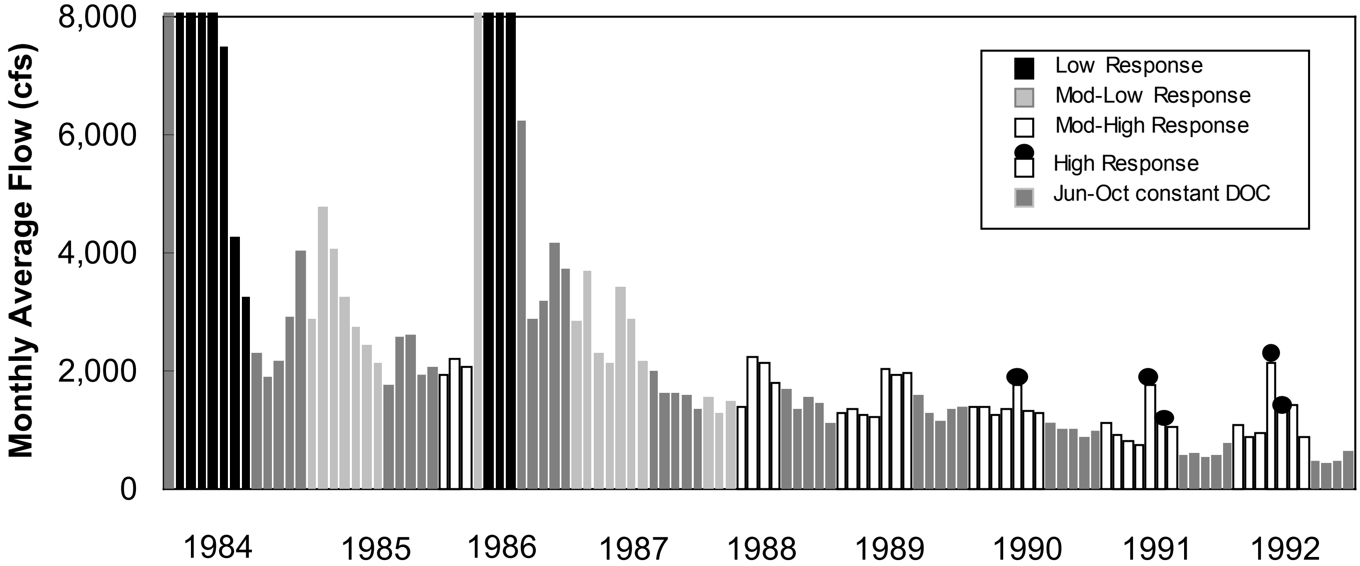


Figure 16. Observed and Generated DOC at Vernalis

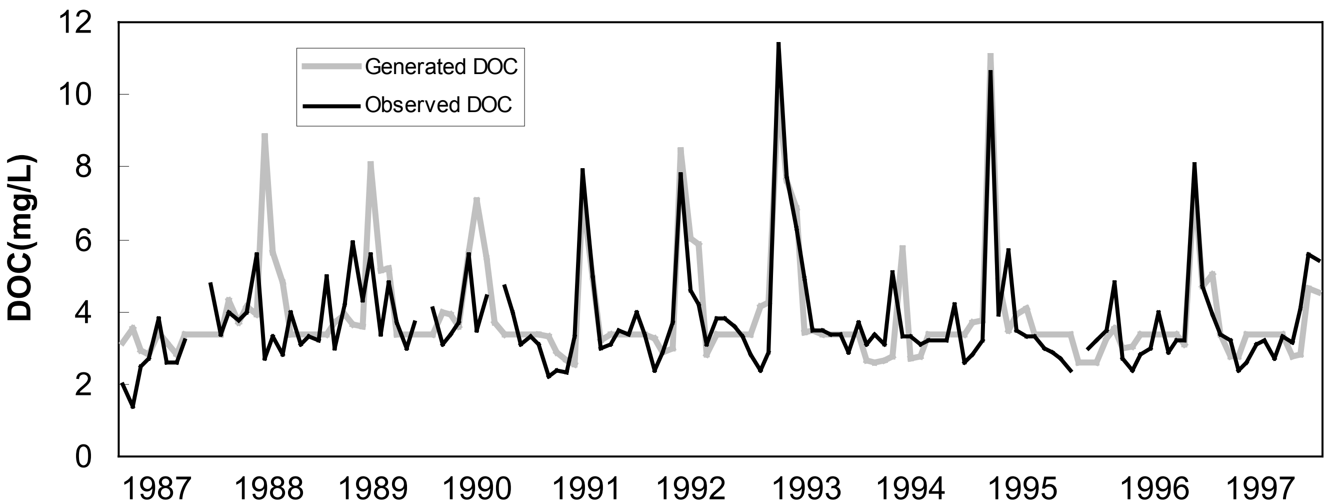


Figure 17. Generated DOC at Vernalis

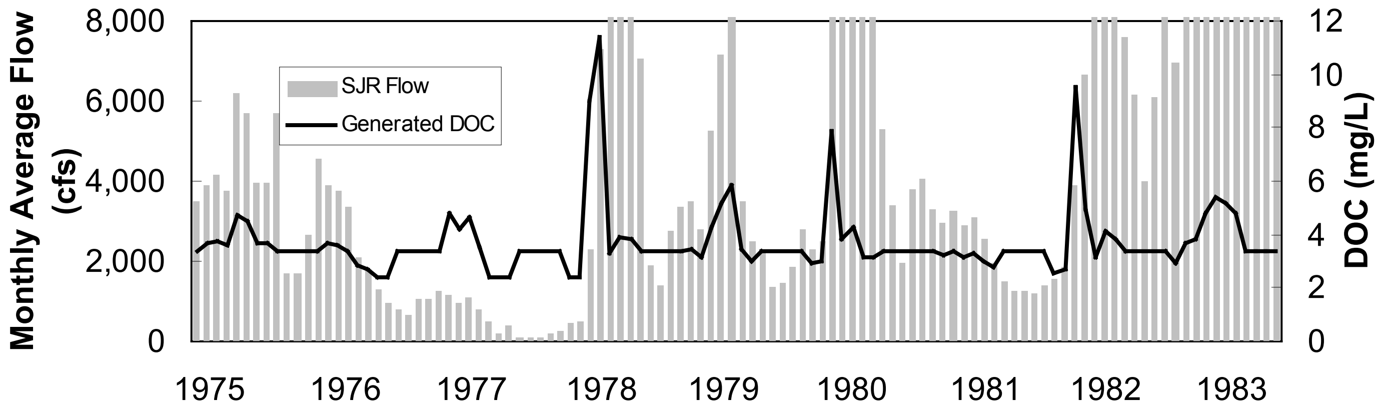


Figure 17. Generated DOC at Vernalis

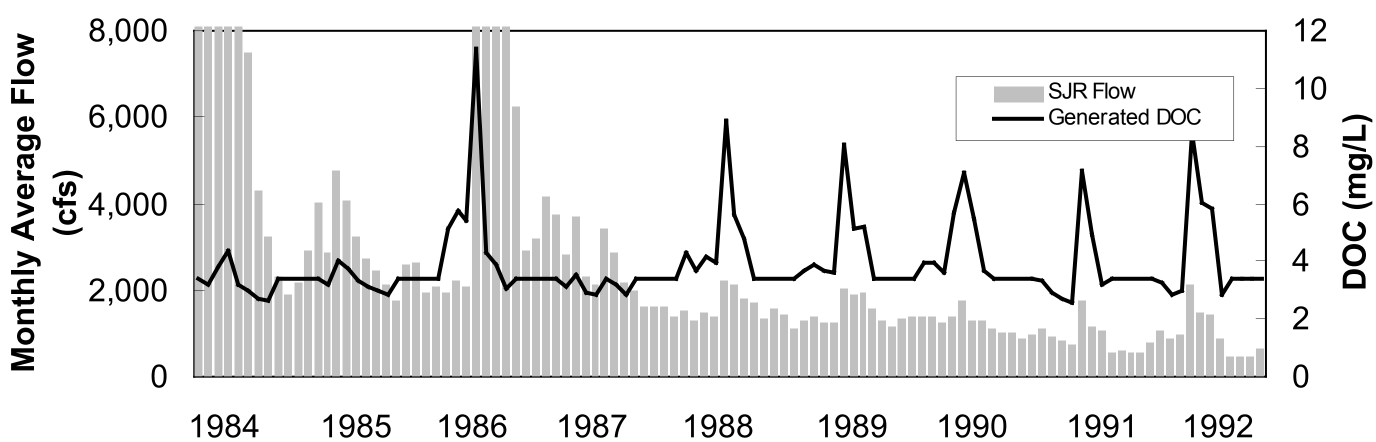


Table 5. Generated DOC at Vernalis (values in mg/L)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975	3.38	3.64	3.76	3.58	4.71	4.47	3.67	3.68	3.38	3.38	3.38	3.38
1976	3.38	3.65	3.57	3.38	2.82	2.68	2.44	2.40	3.38	3.38	3.38	3.38
1977	3.38	4.83	4.20	4.66	3.56	2.40	2.40	2.40	3.38	3.38	3.38	3.38
1978	3.38	2.40	2.40	8.99	11.40	3.27	3.91	3.84	3.38	3.38	3.38	3.38
1979	3.38	3.46	3.14	4.26	5.14	5.84	3.46	3.01	3.38	3.38	3.38	3.38
1980	3.38	2.91	2.99	7.89	3.80	4.30	3.17	3.15	3.38	3.38	3.38	3.38
1981	3.38	3.35	3.20	3.34	3.17	3.28	3.01	2.75	3.38	3.38	3.38	3.38
1982	3.38	2.56	2.69	9.51	4.91	3.16	4.13	3.80	3.38	3.38	3.38	3.38
1983	3.38	2.93	3.64	3.84	4.78	5.41	5.14	4.79	3.38	3.38	3.38	3.38
1984	3.38	3.22	3.84	4.34	3.21	2.97	2.73	2.65	3.38	3.38	3.38	3.38
1985	3.38	3.16	4.05	3.72	3.34	3.11	2.97	2.82	3.38	3.38	3.38	3.38
1986	3.38	5.15	5.76	5.44	11.40	4.28	3.87	3.06	3.38	3.38	3.38	3.38
1987	3.38	3.15	3.55	2.90	2.83	3.42	3.16	2.85	3.38	3.38	3.38	3.38
1988	3.38	4.30	3.70	4.16	3.93	8.86	5.63	4.82	3.38	3.38	3.38	3.38
1989	3.38	3.69	3.91	3.65	3.60	8.06	5.12	5.19	3.38	3.38	3.38	3.38
1990	3.38	3.98	3.93	3.62	5.66	7.10	5.46	3.70	3.38	3.38	3.38	3.38
1991	3.38	3.34	2.90	2.67	2.54	7.17	4.94	3.19	3.38	3.38	3.38	3.38
Avg	3.38	3.51	3.60	4.70	4.75	4.69	3.84	3.42	3.38	3.38	3.38	3.38

Figure 18. Monthly Average Observed and Generated DOC at Vernalis

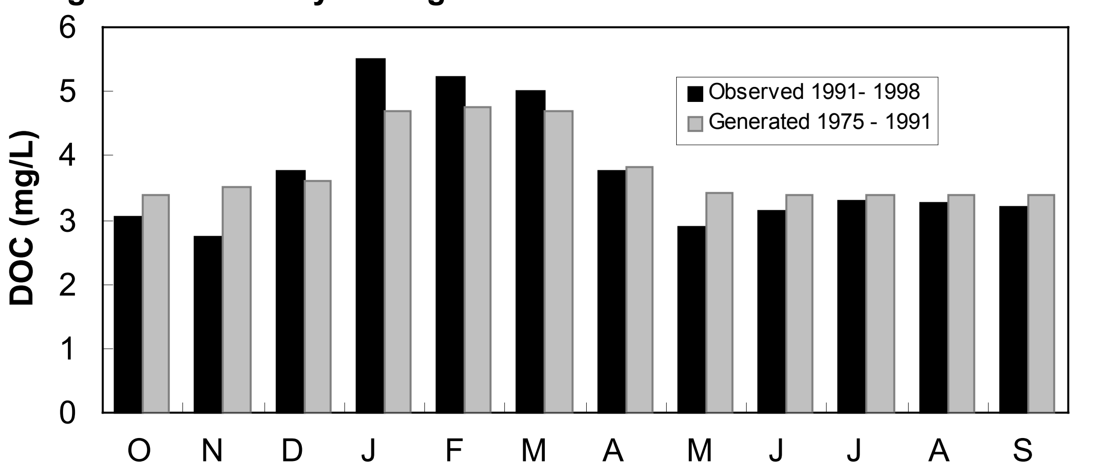


Figure 19. Observed UVA vs Observed DOC at Vernalis/Mossdale

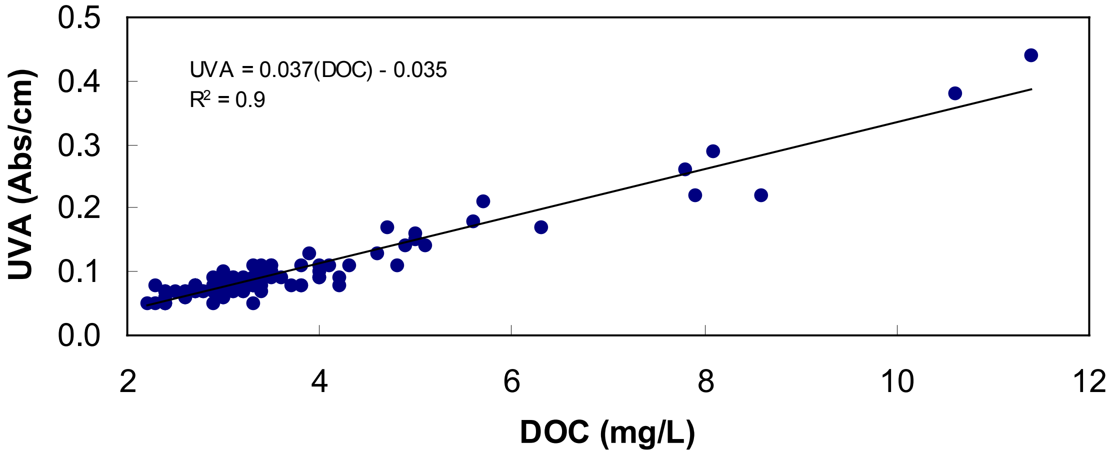
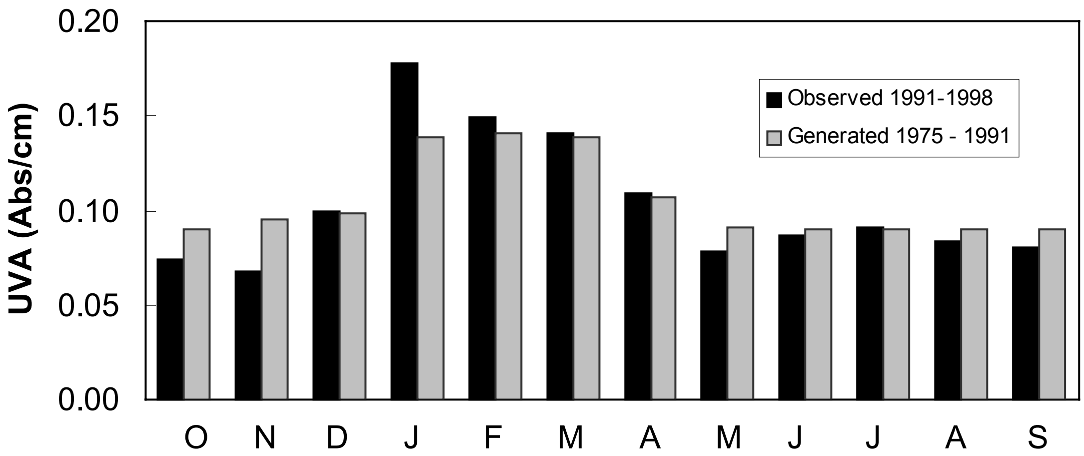


Table 6. Generated UVA at Vernalis (values in Abs/cm)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975	0.09	0.10	0.10	0.10	0.14	0.13	0.10	0.10	0.09	0.09	0.09	0.09
1976	0.09	0.10	0.10	0.09	0.07	0.06	0.06	0.05	0.09	0.09	0.09	0.09
1977	0.09	0.14	0.12	0.14	0.10	0.05	0.05	0.05	0.09	0.09	0.09	0.09
1978	0.09	0.05	0.05	0.30	0.39	0.09	0.11	0.11	0.09	0.09	0.09	0.09
1979	0.09	0.09	0.08	0.12	0.16	0.18	0.09	0.08	0.09	0.09	0.09	0.09
1980	0.09	0.07	0.08	0.26	0.11	0.12	0.08	0.08	0.09	0.09	0.09	0.09
1981	0.09	0.09	0.08	0.09	0.08	0.09	0.08	0.07	0.09	0.09	0.09	0.09
1982	0.09	0.06	0.06	0.32	0.15	0.08	0.12	0.11	0.09	0.09	0.09	0.09
1983	0.09	0.07	0.10	0.11	0.14	0.16	0.15	0.14	0.09	0.09	0.09	0.09
1984	0.09	0.08	0.11	0.13	0.08	0.07	0.07	0.06	0.09	0.09	0.09	0.09
1985	0.09	0.08	0.11	0.10	0.09	0.08	0.07	0.07	0.09	0.09	0.09	0.09
1986	0.09	0.16	0.18	0.17	0.39	0.12	0.11	0.08	0.09	0.09	0.09	0.09
1987	0.09	0.08	0.10	0.07	0.07	0.09	0.08	0.07	0.09	0.09	0.09	0.09
1988	0.09	0.12	0.10	0.12	0.11	0.29	0.17	0.14	0.09	0.09	0.09	0.09
1989	0.09	0.10	0.11	0.10	0.10	0.26	0.15	0.16	0.09	0.09	0.09	0.09
1990	0.09	0.11	0.11	0.10	0.17	0.23	0.17	0.10	0.09	0.09	0.09	0.09
1991	0.09	0.09	0.07	0.06	0.06	0.23	0.15	0.08	0.09	0.09	0.09	0.09
Avg	0.09	0.09	0.10	0.14	0.14	0.14	0.11	0.09	0.09	0.09	0.09	0.09

Figure 20. Monthly Average Observed and Generated UVA at Vernalis



Mokelumne River DOC and UVA

Due to insufficient data, observed DOC from the American River was used to generate DOC for the Mokelumne River. Figure 21 shows historic DOC and flow in the American River. DOC from June through October was averaged to yield a single value of 1.66 mg/L to approximate monthly DOC each year during this interval for the planning period (Figure 22). Unlike Greens Landing and Vernalis, DOC in the American River in other months exhibited no apparent pattern with flows and therefore was simply averaged to yield two alternative values of DOC (Figure 23):

Low DOC = 1.74 mg/L High DOC = 3.95 mg/L

These DOC values were then associated with flow in the Mokelumne River over the planning period, with 4.00 mg/L assigned to the first higher flows in the winter, 1.66 mg/L to June through October, and 1.74 mg/L to all other months (Figure 24, Table 7). The average DOC generated in the Mokelumne River by this process over the planning period was similar to the average observed DOC (Figure 25).

UVA in the Mokelumne River was generated by applying a regression based on historic DOC and UVA to the generated DOC (Figure 26, Table 3). Average generated UVA in the Mokelumne River over the planning period was consistent with the average observed UVA (Figure 27).

Figure 21. Observed DOC and Flow in the American River

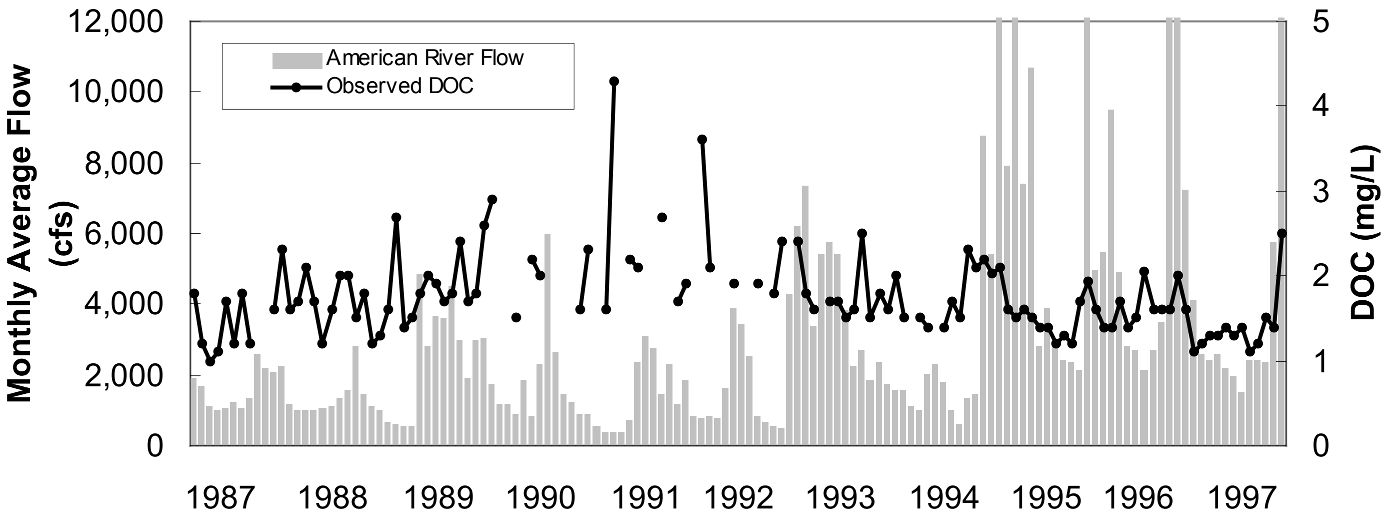


Figure 22. Observed DOC in American River, 1987 - 1997
(grouped by month)

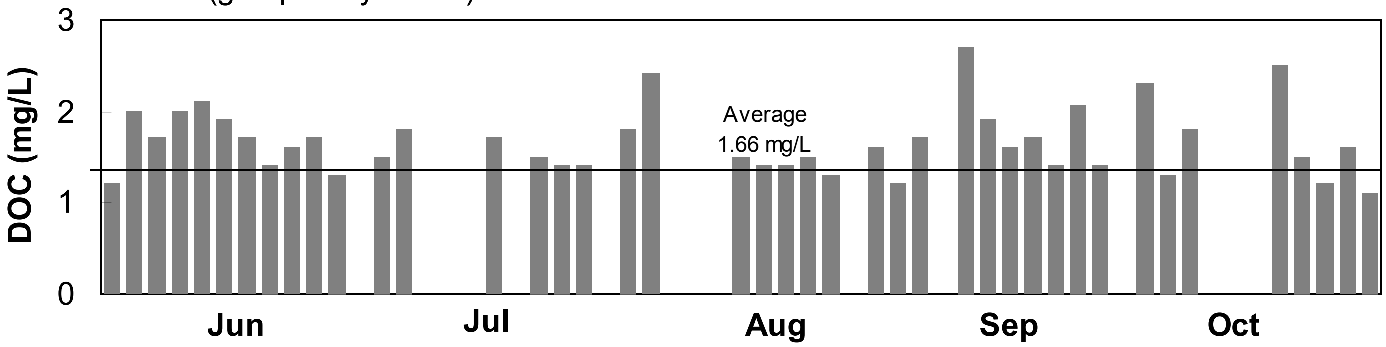


Figure 23. Flow and Observed DOC in the American River
(June - October Values Removed)

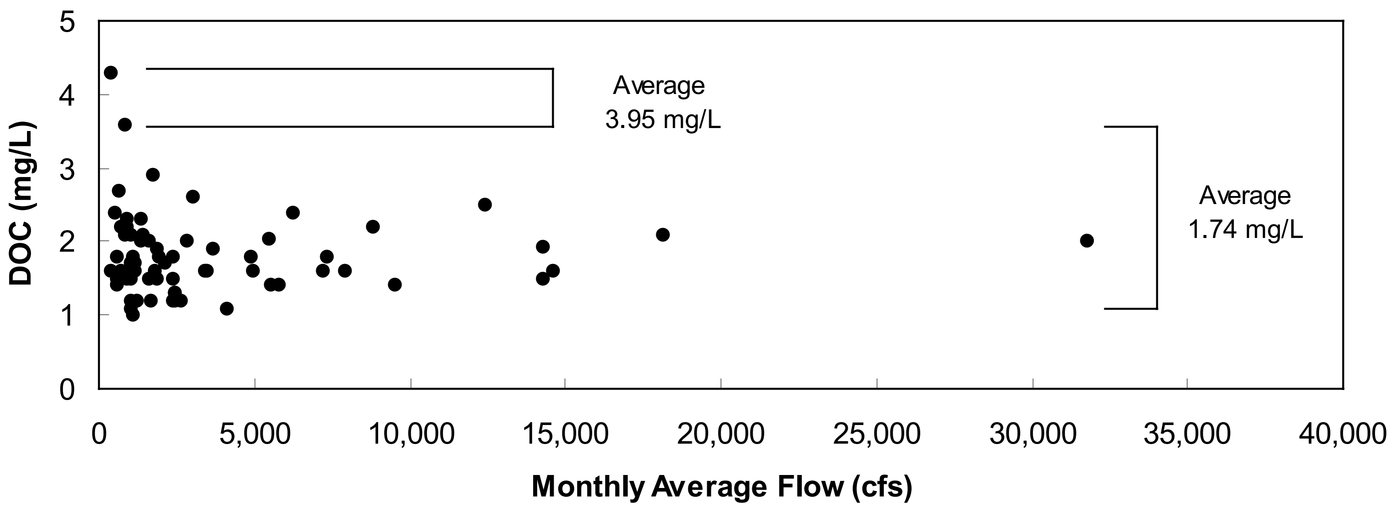


Figure 24. Generated DOC in Mokelumne River

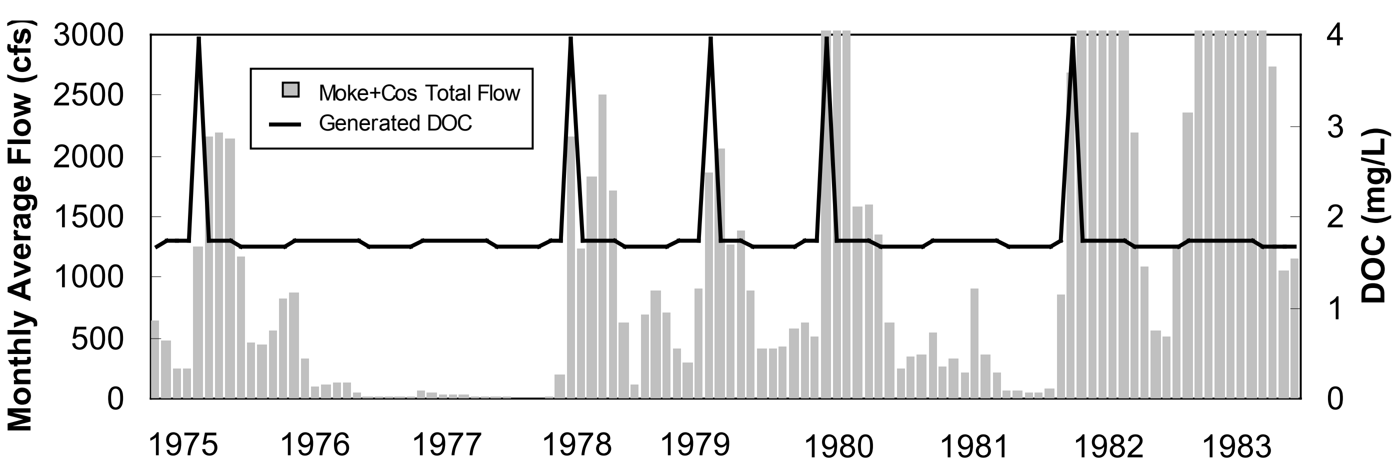


Figure 24. Generated DOC in Mokelumne River

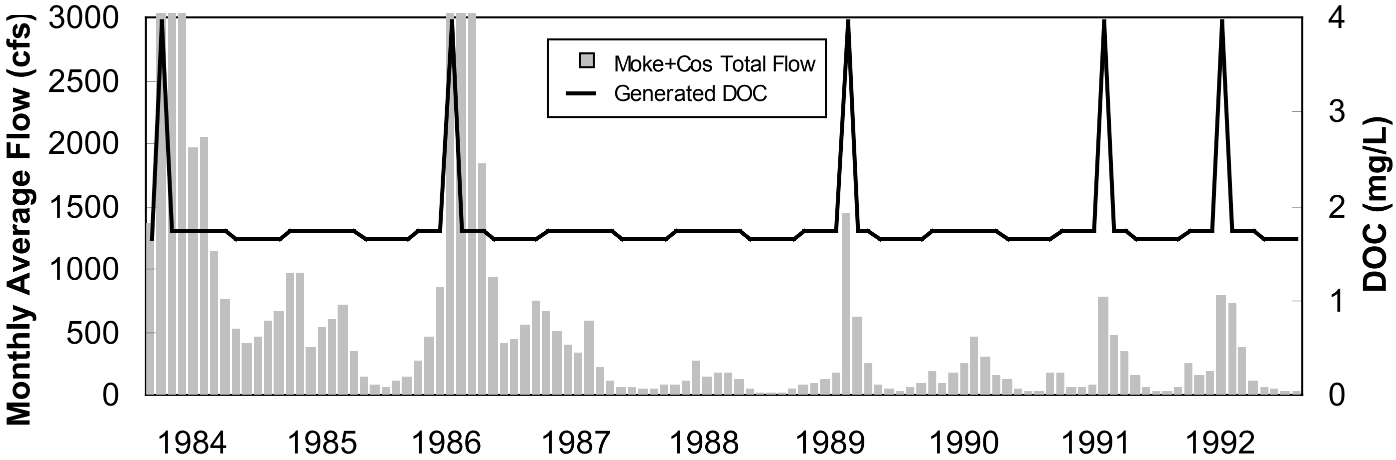


Table 7. Generated DOC in Mokelumne River (values in mg/L)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975	1.66	1.74	1.74	1.74	3.95	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1976	1.66	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1977	1.66	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1978	1.66	1.74	1.74	3.95	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1979	1.66	1.74	1.74	1.74	3.95	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1980	1.66	1.74	1.74	3.95	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1981	1.66	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1982	1.66	1.74	3.95	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1983	1.66	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1984	1.66	3.95	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1985	1.66	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1986	1.66	1.74	1.74	1.74	3.95	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1987	1.66	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1988	1.66	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1989	1.66	1.74	1.74	1.74	1.74	3.95	1.74	1.74	1.66	1.66	1.66	1.66
1990	1.66	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.66	1.66	1.66	1.66
1991	1.66	1.74	1.74	1.74	1.74	3.95	1.74	1.74	1.66	1.66	1.66	1.66
Avg	1.66	1.87	1.87	2.00	2.13	2.00	1.74	1.74	1.66	1.66	1.66	1.66

Figure 25. Monthly Average Observed and Generated DOC in Mokelumne River

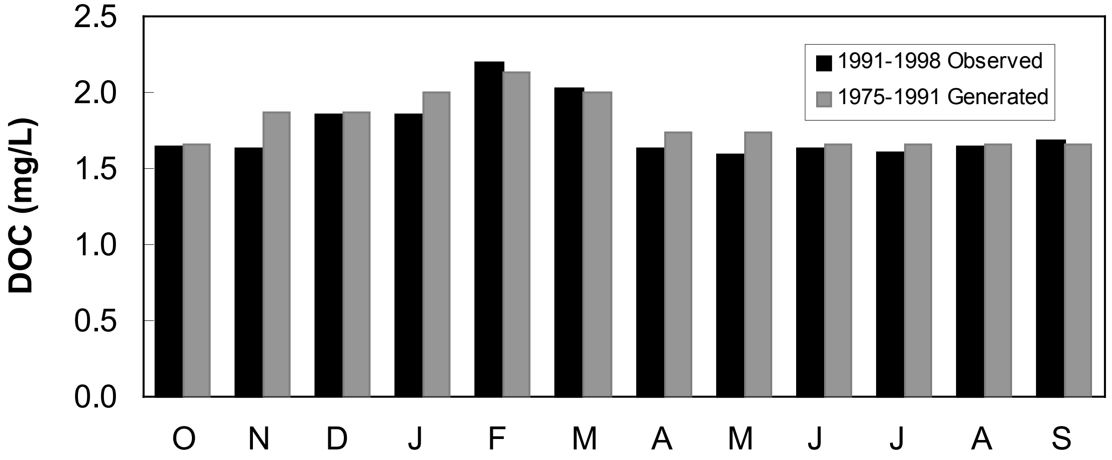


Figure 26. Observed UVA vs Observed DOC in Mokelumne River

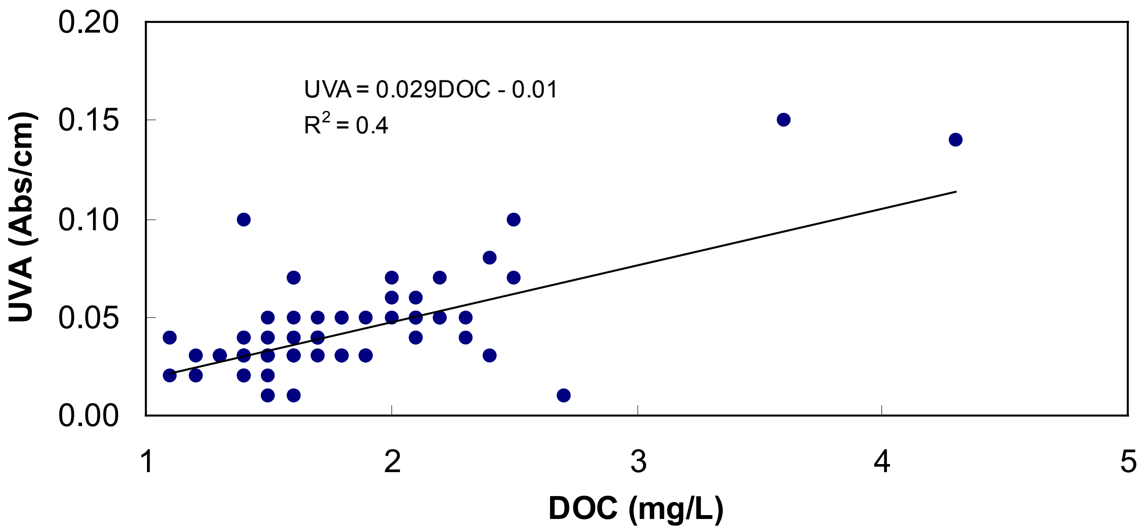
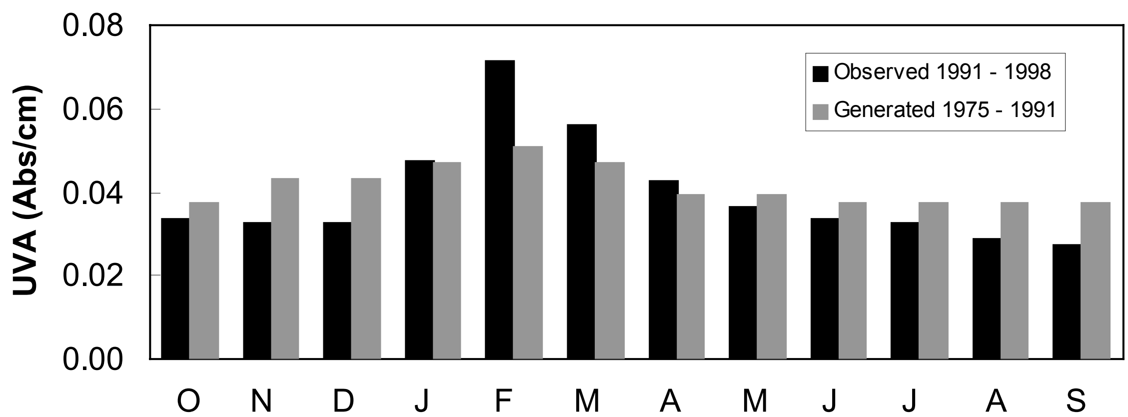


Table 8. Generated UVA in Mokelumne River (values in Abs/cm)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975	0.04	0.04	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1976	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1977	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1978	0.04	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1979	0.04	0.04	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1980	0.04	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1981	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1982	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1983	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1984	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1985	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1986	0.04	0.04	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1987	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1988	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1989	0.04	0.04	0.04	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04
1990	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1991	0.04	0.04	0.04	0.04	0.04	0.10	0.04	0.04	0.04	0.04	0.04	0.04
Avg	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04

Figure 27. Monthly Average Observed and Generated UVA in Mokelumne River



OFFICE MEMO

TO: Paul Hutton	**DATE:** November 19, 2001
FROM: Sanjaya Seneviratne	**SUBJECT:** Development of Flow salinity Relationships for CALSIM

CALSIM operates under many constraints to compute the inflows and exports into the Delta. At several key locations in the Delta, salinity standards are established depending on how the system is operated. CALSIM has to provide enough inflows or should cut exports to meet the salinity standards at all locations.

CALSIM used G model to determine the Net Delta Outflow (NDO) to meet the salinity standards at different locations in the Delta. The flow salinity relationship used in G model is almost exclusively dependent on the Net Delta Outflow. Because G model does not take into considerations the internal plumbing of the Delta such as the Delta Cross Channel Operation, the predictions made by the G model in the Central Delta could be more desired. The Artificial Neural Network (ANN) uses inflows of Sacramento, San Joaquin, East Side Streams and Yolo By Pass, the exports of CVP, SWP, CCC, NB and Vallejo, the Channel Depletions due to Drainage, Seepage and Irrigation and the operation of the Delta Cross Channel to predict the salinity at different locations in the Delta.

DSM2 (2001 Calibration) was used to calculate the EC at Jersey Point, Emmaton, Old River at Rock Slough and Collinsville for different inflows and exports. Monthly averaged flows and exports from CALSIM and daily EC values generated from DSM2 between 1975 and 1991 were fed into the Stuttgard Neural Network Simulator to calibrate the ANN. This calibrated Artificial Neural Network was fed back in to the CALSIM model. Please refer to Chapter 7 of the August 2001 Annual Progress Report to the State Water Resources Control Board for a detailed description of how ANN was integrated into CALSIM.

To ensure that the ANN produced the desired results, a full circle analysis was done. The methodology is described in Chapter 8 of the above report. Salinity calculated using ANN and DSM2 matched very well for Jersey Point, Emmaton and Collinsville. ANN calculated EC at Rock Slough had a slight over prediction when compared to DSM2 results. To overcome this problem, a multiple regression analysis was performed between Rock Slough EC and Jersey Point EC for the current month and the previous month. This regression relationship used ANN calculated Jersey Point EC to calculate Rock Slough EC.

When the Delta Modeling Section work plan was developed for the In-Delta Storage investigation the intention was to develop flow salinity relationships for all diversion and export locations using daily varying hydrology. If these were developed CALSIM would have been better able to release the required amount of water to meet export standards. Due to time constraints and the complexity in integrating daily ANN into the daily CALSIM, this work was postponed to a later date. Development of the organic ANN to predict Dissolved Organic Carbon concentrations was also postponed indefinitely due to time constraints.

OFFICE MEMO

TO: Sushil Arora	**DATE:** May 29, 2001
FROM: Paul Hutton	**SUBJECT:** ISI In-Delta Storage: CALSIM Water Quality Constraints to Meet Delta Wetlands WQMP **DRAFT**

The purpose of this memo is to propose CALSIM water quality constraints for evaluating ISI In-Delta Storage Project water supply benefits. Translation of water quality constraints into CALSIM operating rules is discussed in a separate memo to you. For convenience, this memo loosely refers to both the In-Delta Storage Project and the Delta Wetlands Project as the "Project".

Water quality constraints were developed for total organic carbon (TOC), disinfection by-product (DBP) formation and chloride in accordance with Attachments 2 and 3 of the Delta Wetlands Water Quality Management Plan (WQMP) and water quality objectives outlined in the SWRCB's Decision 1643 for the Project. By employing several assumptions, many of which are specified in the WQMP, the constraints were defined in terms of ambient water temperature and three DSM2 simulation constituents -- dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UVA), and electrical conductivity (EC). DOC is employed as a surrogate for TOC; EC is employed as a surrogate for bromide and chloride.

CALSIM requires information on how to operate the Project while meeting the water quality constraints proposed in this memo. The information must guide model decisions related to magnitude and timing of Project storage diversions and releases. An artificial neural network (ANN) emulation of DSM2 can directly provide some of the necessary information to CALSIM. CALSIM is currently provided salinity-based (EC) water quality conditions at three Delta locations (Old River at Rock Slough, San Joaquin River at Jersey Point, and Sacramento River at Emmaton) through an ANN flow-salinity routine trained on DSM2 output data. The Delta Modeling Section will develop new ANNs that emulate DSM2 simulations of EC, DOC and UVA at Project diversions and key urban intakes. Regression relationships will be utilized to transform bromide and chloride constraints into EC constraints. Until these ANNs are developed, simple Project operating rules will be developed to approximately meet the water quality constraints.

General Notes on Water Quality Operational Constraints

<u>Urban Intakes</u>

The WQMP preamble identifies the following urban intakes as having the potential to be negatively impacted by the Project: Banks Pumping Plant, Tracy Pumping Plant, CCC PP #1, and CCWD's Los Vaqueros and Mallard Slough intakes. Each of these locations will be modeled in DSM2 simulations. However, for the purposes of CALSIM modeling, I recommend that we initially focus on the first four locations. DSM2 post analysis will indicate the need to consider other locations in CALSIM.

<u>Uncertainty Factor</u>

Attachment 2 of the WQMP establishes an uncertainty factor of ± 5% for determining an exceedance of TOC and DBP formation constraints. While this factor may be useful in evaluating performance in DSM2, I recommend that this factor generally not be invoked for CALSIM operations. The exception to this recommendation is when a DBP constraint is exceeded in a CALSIM base study. Under such a condition, David Forkel interprets the WQMP as allowing the Project to impact DBP concentrations by as much as 5% of the DBP standard. See text below on DBP formation constraints for total trihalomethanes and bromate.

14-Day Averages

In accordance with Attachment 2 of the WQMP, the TOC, DBP and chloride constraints will be enforced as 14-day averages, or the averages for the duration of Project discharge, whichever time period is less.

Temperature & Dissolved Oxygen Constraints

D-1643 sets limits on Project discharge to avoid adverse impacts due to dissolved oxygen depression and water temperature increases. These limits generally relate to the immediate receiving waters (although the DO limit also applies to a reach of the San Joaquin River between Turner Cut and Stockton.) DWR/USBR should investigate whether these limits will have a practical impact on Project yield. However, the Delta Modeling Section does not plan to develop CALSIM constraints for temperature and DO.

DOC Concentration Constraints

Paragraph A of Attachment 2 of the WQMP states that the Project cannot cause an increase in TOC of more than 1.0 mg/L and it cannot cause TOC to exceed 4.0 mg/L. The 5% uncertainty factor is not incorporated into the constraint. For purposes of DSM2 and CALSIM modeling, DOC concentration will be assumed equivalent to TOC concentration and the urban intake constraints may be stated mathematically as follows:

DOC (w/o Project)	DOC (w/ Project) – DOC (w/o Project)
0.0 – 3.0 mg/L	≤ 1.0 mg/L
3.0 – 4.0 mg/L	linear decrease in constraint value from ≤ 1.0 to ≤ 0.0 mg/L
> 4.0 mg/L	≤ 1.0 mg/L

DBP Formation Constraint: Total Trihalomethanes (TTHM)

Paragraph B.1 of Attachment 2 of the WQMP states that the Project cannot cause or contribute to TTHM concentrations in excess of 64 ug/L, as calculated in the raw water of urban intakes in the Delta. If without project conditions exceed 64 ug/L, the Project is allowed to impact TTHM up to 5% of 64 ug/L, or 3.2 ug/L. This constraint can be defined mathematically as follows:

TTHM (w/o Project)	TTHM (w/ Project) – TTHM (w/o Project)
0.0 – 60.8 ug/L	linear decrease in constraint value from ≤ 64.0 to ≤ 3.2 ug/L
> 60.8 ug/L	≤ 3.2 ug/L

where:

$$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48} \quad \ldots\ldots\ldots(1)$$

and:

TTHM = total trihalomethane concentration (ug/L)
C1 = 14.5 when DOC < 4.0 mg/L; C1 = 12.5 when DOC ≥ 4.0 mg/L
DOC = raw water dissolved organic carbon (mg/L) as simulated by DSM2
UVA = raw water ultraviolet absorbance at 254nm (1/cm) as simulated by DSM2
Br = raw water bromide concentration (mg/L) as simulated by DSM2
T = raw water temperature (°C)

Attachment 1 tabulates raw water temperatures for use in Eq. (1). The values in Attachment 1 are assumed to represent all years and all urban intakes in the Delta. Derivation of Eq. (1) is provided in Attachment 2. DSM2 salinity simulations will be conducted in terms of EC and ANN results will report salinity results in terms of EC. Attachment 3 develops the above equation in terms of EC instead of Br for the four key urban intakes.

DBP Formation Constraint: Bromate (BRM)

Paragraph B.2 of Attachment 2 of the WQMP states that the Project cannot cause or contribute to bromate concentrations in excess of 8 ug/L, as calculated in the raw water of urban intakes in the Delta. If base conditions exceed 8 ug/L, the Project is allowed to impact bromate up to 5% of 8 ug/L, or 0.4 ug/L. This constraint can be defined mathematically as follows:

Bromate (w/o Project)	Bromate (w/ Project) – Bromate (w/o Project)
0.0 – 7.6 ug/L	linear decrease in constraint value from ≤ 8.0 to ≤ 0.4 ug/L
> 7.6 ug/L	≤ 0.4 ug/L

where:

$$BRM = C2 \times DOC^{0.31} \times Br^{0.73} \quad \text{……………………………………………………………………(2)}$$

and:

BRM = bromate concentration (ug/L)
C2 = 9.6 when DOC < 4.0 mg/L; C = 9.2 when DOC ≥ 4.0 mg/L
DOC = raw water dissolved organic carbon (mg/L) as simulated by DSM2
Br = raw water bromide concentration (mg/L) as simulated by DSM2

Derivation of Eq. (2) is provided in Attachment 4. Attachment 5 develops the above equation in terms of EC instead of Br for the four key urban intakes.

Chloride Concentration Constraints

Paragraph C of Attachment 2 of the WQMP states that the Project cannot cause an increase in chloride of more than 10 mg/L and it cannot cause or contribute to any salinity increases at urban intakes exceeding 90% of adopted salinity standards. These constraints may be stated mathematically as follows (see Attachment 6 for a restatement in terms of EC):

Chloride (w/o Project)	Chloride (w/ Project) – Chloride (w/o Project)
At CCC PP#1 when 150 mg/L standard controls:	
0.0 – 135 mg/L	≤ 10 mg/L
> 135 mg/L	≤ 0 mg/L
At urban intakes when CCC PP #1 150 mg/L standard does not control:	
0.0 – 225 mg/L	≤ 10 mg/L
> 225 mg/L	≤ 0 mg/L

Long-Term Constraints

Paragraph F.3 of the WQMP discusses mitigation of long-term water quality impacts associated with the Project. The paragraph quantifies what is considered to be an unacceptable long-term impact.

However, the period of time considered to be "long-term" is not well defined. The Project is required to mitigate 150% of the net increase in TOC and salt (i.e. TDS, bromide and chloride) loading greater than 5% in the urban diversions due to Project operations. Based upon other wording in Paragraph F, I propose the constraint be written as follows:

[DOC (w/ Project) – DOC (w/o Project)] / DOC (w/o Project) $\leq$ 0.05 ……..……………………(5)
[EC (w/ Project) – EC (w/o Project)] / EC (w/o Project) $\leq$ 0.05 ………..………………………..(6)

where DOC and EC are calculated as flow-weighted 3-year running averages. I propose that these constraints not be dynamically implemented in CALSIM. Rather, these constraints would be checked in a DSM2 post analysis. If a long-term constraint is violated for a particular alternative, an iterative solution could be found by buffering the DOC or salt constraints in CALSIM.

Attachments

Cc: Sanjaya Seneviratne
Tara Smith
Dan Otis

ATTACHMENT 1
RAW WATER TEMPERATURES

Temperature data were acquired from David Forkel of Delta Wetlands. These data were utilized in their work with CUWA, and came from CCWD water treatment plant averages as provided by KT Shum. An interpolation scheme was used to generate daily values from the monthly averages tabulated below.

Data from the IEP web site are also tabulated below for comparison only. D-1485 discrete water quality sampling data at Clifton Court Forebay were evaluated for the period 1975-93 to develop the monthly average values. Temperature was measured once or twice each month during the late morning and afternoon hours. Another data set was used to evaluate diurnal variations. This analysis indicted less than 2 degrees variation over a 24-hour period, which is within the standard deviation of the tabulated monthly averages.

Month	Temperature (°C)	
	CCWD	Clifton Court
January	9	9
February	12	11
March	15	14
April	20	16
May	23	19
June	24	22
July	24	24
August	24	24
September	23	22
October	20	20
November	15	15
December	11	10

ATTACHMENT 2
DERIVATION OF THE TTHM CONSTRAINT

The Malcolm Pirnie equation in Attachment 3 of the WQMP is as follows:

$$TTHM = 7.21 \times TOC^{0.004} \times UVA^{0.534} \times (Cl2 - 7.6 \times NH3N)^{0.224} \times t^{0.255} \times (Br + 1)^{2.01} \times (pH - 2.6)^{0.719} \times T^{0.48}$$

where:

TTHM = total trihalomethane concentration (ug/L)
TOC = total organic carbon concentration after enhanced coagulation (mg/L)
UVA = ultraviolet absorbance at 254 nm after enhanced coagulation (1/cm)
Cl2 = available chlorine after enhanced coagulation (mg/L)
NH3N = ammonia concentration after enhanced coagulation (mg/L as Nitrogen)
t = chlorine contact time (hrs)
Br = raw water bromide concentration (mg/L)
pH = water pH after enhanced coagulation
T = raw water temperature (°C)

By employing several assumptions, the above equation reduces to a relationship that depends only on raw water temperature and three raw water constituents simulated by DSM2. Assumptions are per Attachment 3 of the WQMP unless noted otherwise:

1. Enhanced coagulation removes a fraction of TOC from raw water:
   a. TOC = 0.75 x raw water TOC if raw water TOC < 4 mg/L
   b. TOC = 0.65 x raw water TOC if raw water TOC ≥ 4 mg/L
2. DOC and raw water TOC are assumed to be equivalent (per B. Agee MWQI):
   a. DOC = raw water TOC
3. Enhanced coagulation removes a fraction of UVA from raw water (per data provided by S. Krasner MWDSC):
   a. UVA = 0.57 x raw water UVA if raw water TOC < 4 mg/L
   b. UVA = 0.46 x raw water UVA if raw water TOC ≥ 4 mg/L
4. Chlorine dose is sufficient to remove ammonia with free available chlorine in proportion to TOC:
   a. NH3N = 0
   b. Cl2 = TOC
5. t = 1 hr
6. pH = 7

When DOC < 4.0 mg/L:

$$TTHM = 7.21 \times (0.75 \times DOC)^{0.004} \times (0.57 \times UVA)^{0.534} \times (0.75 \times DOC)^{0.224} \times 1^{0.255} \times (Br + 1)^{2.01} \times (7 - 2.6)^{0.719} \times T^{0.48}$$

$$TTHM = 14.5 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48}$$

When DOC ≥ 4.0 mg/L:

$$TTHM = 7.21 \times (0.65 \times DOC)^{0.004} \times (0.46 \times UVA)^{0.534} \times (0.65 \times DOC)^{0.224} \times 1^{0.255} \times (Br + 1)^{2.01} \times (7 - 2.6)^{0.719} \times T^{0.48}$$

$$TTHM = 12.5 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48}$$

ATTACHMENT 3
DERIVATION OF TTHM CONSTRAINT AS A FUNCTION OF EC

The TTHM constraint was derived in Attachment 2 as follows:

$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48}$

where:

TTHM = total trihalomethane concentration (ug/L)
C1 = 14.5 when DOC < 4.0 mg/L; C1 = 12.5 when DOC ≥ 4.0 mg/L
DOC = raw water dissolved organic carbon (mg/L) as simulated by DSM2
UVA = raw water ultraviolet absorbance at 254nm (1/cm) as simulated by DSM2
Br = raw water bromide concentration (mg/L) as simulated by DSM2
T = raw water temperature (°C)

DSM2 salinity simulations will be conducted in terms of EC and ANN results will report salinity results in terms of EC. Therefore, the above equation must be re-written in terms of EC instead of Br, requiring regression relationships between EC and Br at Old River at Rock Slough and other urban intakes. Development of necessary equations and related assumptions is documented in a May 29, 2001 memo from Bob Suits to Paul Hutton.

Old River at Rock Slough

The relationship between EC at Old River at Rock Slough and bromide at CCC PP #1 is as follows:

$Br = -0.114 + 0.00096\ EC$ for EC ≥ 129 uS/cm
$Br = 0.01$ mg/L for EC < 129 uS/cm

where bromide is in mg/L and EC is in uS/cm. Substituting into the TTHM equation yields:

$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (0.886 + 0.00096\ EC)^{2.01} \times T^{0.48}$ for EC ≥ 129 uS/cm

$TTHM = 1.02 \times C1 \times DOC^{0.228} \times UVA^{0.534} \times T^{0.48}$ for EC < 129 uS/cm

Other Urban Intakes

The relationship between EC and Br at the other urban intakes (Banks Pumping Plant, Tracy Pumping Plant, and LVR intake) is as follows:

$Br = -0.185 + 0.00098\ EC$ for EC ≥ 199 uS/cm
$Br = 0.01$ mg/L for EC < 199 uS/cm

where bromide is in mg/L and EC is in uS/cm. Substituting into the TTHM equation yields:

$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (0.815 + 0.00098\ EC)^{2.01} \times T^{0.48}$ for EC ≥ 199 uS/cm

$TTHM = 1.02 \times C1 \times DOC^{0.228} \times UVA^{0.534} \times T^{0.48}$ for EC < 199 uS/cm

ATTACHMENT 4
DERIVATION OF THE BROMATE CONSTRAINT

The Ozekin equation in Attachment 3 of the WQMP is as follows:

$BRM = 1.63\ E\text{-}06 \times TOC^{-1.26} \times pH^{5.82} \times O3DOSE^{1.57} \times Br^{0.73} \times O3TIME^{0.28} \times BRMCF$

where:

BRM = bromate concentration (ug/L)
TOC = total organic carbon concentration after enhanced coagulation (mg/L)
pH = water pH after enhanced coagulation
O3DOSE = ozone dose (mg/L)
Br = raw water bromide concentration (ug/L)
O3TIME = ozone contact time (minutes)
BRMCF = bromate correction factor

Again, by employing several assumptions, the above equation reduces to a relationship that depends only on two raw water constituents simulated by DSM2. Assumptions are per Attachment 3 of the WQMP unless noted otherwise:

1. Enhanced coagulation removes a fraction of TOC from raw water:
   a. TOC = 0.75 x raw water TOC if raw water TOC < 4 mg/L
   b. TOC = 0.65 x raw water TOC if raw water TOC ≥ 4 mg/L
2. DOC and raw water TOC are assumed to be equivalent (per B. Agee MWQI):
   a. DOC = raw water TOC
3. pH = 7
4. Ozone dose is in proportion to TOC:
   a. O3DOSE = 0.6 x TOC
5. Br (ug/L) = Br (mg/L) x 1000 (to provide units consistent with other constraints)
6. O3TIME = 12 min
7. BRMCF = 0.56

When DOC < 4.0 mg/L:

$BRM = 1.63\ E\text{-}06 \times (0.75 \times DOC)^{-1.26} \times 7^{5.82} \times (0.6 \times 0.75 \times DOC)^{1.57} \times (1000 \times Br)^{0.73} \times 12^{0.28} \times 0.56$

$BRM = 9.6 \times DOC^{0.31} \times Br^{0.73}$

When DOC ≥ 4.0 mg/L:

$BRM = 1.63\ E\text{-}06 \times (0.65 \times DOC)^{-1.26} \times 7^{5.82} \times (0.6 \times 0.65 \times DOC)^{1.57} \times (1000 \times Br)^{0.73} \times 12^{0.28} \times 0.56$

$BRM = 9.2 \times DOC^{0.31} \times Br^{0.73}$

ATTACHMENT 5
DERIVATION OF BROMATE CONSTRAINT AS A FUNCTION OF EC

The bromate constraint was derived in Attachment 4 as follows:

$BRM = C2 \times DOC^{0.31} \times Br^{0.73}$

where:

BRM = bromate concentration (ug/L)
C2 = 9.6 when DOC < 4.0 mg/L; C = 9.2 when DOC ≥ 4.0 mg/L
DOC = raw water dissolved organic carbon (mg/L) as simulated by DSM2
Br = raw water bromide concentration (mg/L) as simulated by DSM2

DSM2 salinity simulations will be conducted in terms of EC and ANN results will report salinity results in terms of EC. Therefore, the above equation must be re-written in terms of EC instead of Br, requiring regression relationships between EC and Br at Old River at Rock Slough and other urban intakes. Development of necessary equations and related assumptions is documented in a May 29, 2001 memo from Bob Suits to Paul Hutton.

<u>Old River at Rock Slough</u>

The relationship between EC at Old River at Rock Slough and bromide at CCC PP #1 is as follows:

$Br = -0.114 + 0.00096\ EC$	for EC ≥ 129 uS/cm
$Br = 0.01$ mg/L	for EC < 129 uS/cm

where bromide is in mg/L and EC is in uS/cm. Substituting into the bromate equation yields:

$BRM = C2 \times DOC^{0.31} \times (-0.114 + 0.00096\ EC)^{0.73}$ for EC ≥ 129 uS/cm

$BRM = 0.035 \times C2 \times DOC^{0.31}$ for EC < 129 uS/cm

<u>Other Urban Intakes</u>

The relationship between EC and Br at the other urban intakes (Banks Pumping Plant, Tracy Pumping Plant, and LVR intake) is as follows:

$Br = -0.185 + 0.00098\ EC$	for EC ≥ 199 uS/cm
$Br = 0.01$ mg/L	for EC < 199 uS/cm

where bromide is in mg/L and EC is in uS/cm. Substituting into the bromate equation yields:

$BRM = C2 \times DOC^{0.31} \times (-0.185 + 0.00098\ EC)^{0.73}$ for EC ≥ 199 uS/cm

$BRM = 0.035 \times C2 \times DOC^{0.31}$ for EC < 199 uS/cm

ATTACHMENT 6
DERIVATION OF CHLORIDE CONSTRAINTS AS FUNCTIONS OF EC

DSM2 salinity simulations will be conducted in terms of EC and ANN results will report salinity results in terms of EC. Therefore, chloride constraints are re-stated in terms of EC below for the key urban intakes utilizing the following conversion equations:

EC (uS/cm) @ Old River at Rock Slough = 89.6 + 3.73 Cl @ CCC PP #1

EC (uS/cm) = 161 + 3.66 Cl @ other urban intakes

The above conversion equations and related assumptions are developed and documented in a May 29, 2001 memo from Bob Suits to Paul Hutton.

Old River at Rock Slough

EC (w/o Project)	EC (w/ Project) – EC (w/o Project)

At CCC PP#1 when 150 mg/L chloride standard controls:

0.0 – 593 uS/cm	≤ 37 uS/cm
> 593 uS/cm	≤ 0 mg/L

At CCC PP #1 when 150 mg/L chloride standard does not control:

0.0 – 929 uS/cm	≤ 37 uS/cm
> 929 uS/cm	≤ 0 mg/L

Other Urban Intakes

EC (w/o Project)	EC (w/ Project) – EC (w/o Project)
0.0 – 984 uS/cm	≤ 37 uS/cm
> 984 uS/cm	≤ 0 mg/L

OFFICE MEMO

TO: Paul Hutton	DATE: November 26, 2001
FROM: Tara Smith	SUBJECT: In Delta Storage: CALSIM Water Quality Operating Rules to Meet Delta Wetlands WQMP:DRAFT

Introduction

CALSIM2 requires operating rules to release flows to meet water supply demands and water quality standards. For the Delta water quality standards, CALSIM2 uses the Artificial Neural Network (ANN) to determine if salinity standards are being met and adjusts water supply in the Delta to meet those standards.

The operation of the In Delta Storage islands will affect water quality in a way that cannot currently be addressed by the ANN. ANN is trained using rimflows, exports, and cross channel gate operations and provides salinity water quality results at select locations. The ANN has not been trained to provide salinity water quality results using a Delta hydrology that includes flows being taken and released from In Delta Storage islands.

Additionally, there are other water quality criteria that have been listed in the Water Quality Management Plan (2000) for the In Delta Storage project that are not addressed in CALSIM2. These include criteria for Total Organic Carbon (TOC), Chloride (Cl), Total Trihalomethanes (TTHM), Bromate (BRM), Disolved Oxygen (DO) , and temperature. The attached table (Table 1) shows a summary of the criteria and these constraints are described in greater detail in Hutton (2001).

The water quality criteria for the In Delta Storage project requires that the water releases from the project islands do not adversely impact the ecosystem (temperature and DO) and do not degrade drinking water quality (TOC, Cl, TTHM, BRM). This paper will address the preliminary work done in determining operating rules for CALSIM2 that will address the In Delta Storage Water Quality criteria. Developing these water quality rules will be an iterative process.

CALSIM2

Since CALSIM2 is not designed for water quality modeling, determining if water quality standards are violated in the Delta is not an easy task. As previously discussed, CALSIM2 uses ANN to determine salinity at selected locations based on flows and Delta Cross Channel operation. Other water quality constraints would require using information available from CALSIM2 such as flows or the time of year and would require implementing water quality modules within the code. In these situations, the processes affecting water quality would be simplified and would be a gross estimate of the effects of project operations.

Also included in this puzzle of operating the reservoir islands are several possible combinations of factors that can influence the operation of the projects. The various possible operations of the project to limit Total Organic Carbon at the urban intake locations is used to illustrate this point. To reduce the amount of TOC released from the islands the following operations could be considered;

1. Water diverted onto the island could not only be based on available water supply but also on the

quality of intake water.

2. The time the water is stored on the island, the temperature of the water and its depth will affect the quality of the water. The amount of release and when it is released could be based on these island storage factors.
3. When the water is released from the project islands, it will have to meet water quality criteria at the urban intake locations. This meeting of the criteria could be addressed in the previous steps but could also be addressed by adjusting the amount of water that can be released.

Determining the operation that will optimize the quality and quantity of water released from the project islands will require iterations and analysis with DSM2.

Discussed below are the various water quality criteria and factors that should be considered in determining operating rules.

Chloride

Diversions onto the project islands and releases from the islands will affect the hydrodynamics of the Delta system and could affect the transport of ocean salinity. This transport would affect the Chloride levels. To address this issue, the ANN would be trained with project island releases and diversions.

The amount of flow diverted onto the reservoir islands should be inversely proportional to the Chloride levels at Old River at Rock Slough (the closest station that ANN determines quality at). As the Chloride levels increase the amount of diversion decreases. Since not all water may be diverted at one time, CALSIM2 will need to calculate the changing concentration in the project reservoirs due to inflows and evaporation/precipitation.

The amount of water released will be determined by the effect on quality that the release water has. If the water has low levels of chloride, then the chloride quality won't be a controlling factor. If releasing the water results in a violation of the 150 mg/l or 250 mg/l standard at Rock Slough, then the amount of water released will be less. To prevent the standard from being violated, the following equation could be used as a preliminary estimate (Wang,2001).

Definintions:

Q_1 = Background flow rate, cfs
Q_2 = Project island release flow rate, cfs
C_1 = Chloride concentration of Q_1, mg/l
C_2 = Chloride concentration of Q_2, mg/l

To Determine Maximum Q_2:
Assuming Q_1 is not changed.

$$\frac{(Q_1 - Q_2)C_1 + Q_2 C_2}{Q_1} \leq 150 \qquad (1)$$

Rearranging the equation gives:

$$Q_2 \leq \frac{(150 - C_1)Q_1}{C_2 - C_1} \qquad (2)$$

Total Organic Carbon

There are three areas that have to be considered when looking at Total Organic Carbon quality and its effects on drinking water quality. The first is the quality of the water diverted onto the project islands, the second is the increase in TOC in the project reservoirs due to the interaction with the peat soil and bioproductivity, and the third area is the release quality and quantity from the project islands.

Diversion of water onto the reservoir islands takes place in excess flow conditions. TOC levels tend to be high during the first big precipitation event. Water diverted to the reservoir island during this time will have higher TOC than the water in the channels during times of reservoir island release. Operating rules may need to consider limiting the amount of water diverted during these events.

While the water stays in the project island reservoir, it interacts with the peat soil and the TOC levels increase (Jung, 2001). Additionally TOC increases due to bioproductivity (Duvall,2001). This increase depends on the length of time the water is there, the depth of the water, and the temperature of the water, among other factors. Operating rules may need to consider these factors in determining when and how much water can be released. A possible operating rule to limit the increase of TOC would be to release the project island water first to meet south of Delta demands instead of releasing from upstream reservoirs. Additionally, a rule to retain a small amount of water in the project island may be made to limit bioproductivity.

Since CALSIM2 does not model the changing Total Organic Carbon or Dissolved Organic Carbon (DOC) levels in the Delta Channels, an attempt was made to correlate DOC with Delta island consumptive use (DICU) with the intention of using the relationship to develop project island diversion rules. No strong correlation was found (Anderson, May 2001).

Using a relationship developed by Jung (Nov 2001), the interaction between the peat soil and the water can be modeled in CALSIM2 (Nader-Tehrani, Nov 2001).

Similar to the rules for chloride, the amount of water released will be determined by the effect on TOC that the release water has. If the water has lower levels of TOC, then the TOC quality won't be a controlling factor. If releasing the water results in a violation of the 1 mg/l criteria, then the amount of water released will be less. As a preliminary estimate of release flows that will not violate the TOC criteria, equation 4 could be used.

Definintions:

Q_1 = Background flow rate, cfs
Q_2 = Project island release flow rate, cfs
C_1 = TOC concentration of Q_1, mg/l
C_2 = TOC concentration of Q_2, mg/l

To Determine Maximum Q_2:

Assuming Q_1 is not changed.

$$\frac{(Q_1 - Q_2)C_1 + Q_2 C_2}{Q_1} \leq C_1 + 1 \qquad (3)$$

Rearranging the equation gives:

$$Q_2 \le \frac{Q_1}{C_2 - C_1} \qquad (4)$$

Bromate

Using the Ozekin equation in attachment 3 of the Water Quality Management Plan (2000) which was further derived and simplified in Hutton (2001), Bromate can be described as a function of Dissolved Organic Carbon and Bromide.

$$BRM = C2 \times DOC^{0.31} \times Br^{0.73} \qquad (3)$$

When water is diverted, stored and released, the combination of DOC and Bromide will also have to be incorporated into the operating constraints. Both DOC and Bromide can be determined using relationships between TOC (Hutton, 2001) and Electrical Conductivity and Chloride (Suits, 2001)

Total Trihalomethanes (TTHM)

Using the Malcolm Pirnie equation in attachment 3 of the Water Quality Management Plan (WQMP) which was further derived and simplified in Hutton (2001), TTHM can be described as a function of Dissolved Organic Carbon, and Bromide, Ultraviolet Absorbance (UVA), and temperature (T).

$$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48} \qquad (4)$$

Temperature and DO

Adequate temperature and DO rules in CALSIM2 will be difficult to implement due to some precise release rules criteria. Even accurately modeling temperature and DO changes due to diversions and releases in DSM2 will be difficult due to inadequate amounts of observed data to calibrate DSM2.

Analysis of the effects of releases on temperature and DO levels is currently being accomplished by using a spreadsheet model to evaluate the local effects (Yokoyama, 2001).

Table 1: Water Quality Criteria, In-Delta Storage Program

WATER QUALITY CRITERIA, IN-DELTA STORAGE PROGRAM

CRITERIA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TOTAL ORGANIC CARBON (TOC)												
All export Locations (14-day average) (1)						<4.0 mg/L limit						
All export locations and Water TP intakes (14-day average) (2)					Incremental Increase <1.0 mg/L							
If TOC of stored water > TOC of channel water (3)		Discharge from Webb Tract or Bacon Island ranges from 40 cfs to 1,500 cfs depending on TOC										
CHLORIDE												
CCWD's intake and any urban water intake in the Delta (4)					< 10 mg/L Chloride							
Any urban intake in the Delta (5)					< 90% of salinity std.							
Limit discharge from Webb Tract and Bacon Island (6)			For chloride 0 - 250 mg/L, discharge 3,000 - 80 cfs									
DISINFECTION BYPRODUCTS (TTHM)												
Urban intake or treatment plant outlet (7)					< 64 µg/ L TTHM							
BROMATE												
Urban intake or treatment plant outlet (8)					< 8 µg/ L Bromate							
DISOLVED OXYGEN (DO)												
No discharge if DO in stored water is less than: (9)						< 6 mg/L						
No discharge if depressesDO of channel water to less: (10)						< 5.0 mg/L						
No discharge if DO in San Joaquin (Turner Cut to Stockton) (11)									< 6.0 mg/L			
TEMPERATURE												
No discharge if temperature differential (12)						>20° F						
For channel temp. 55° F to 66° F, limit increase to (13)						< 4° F						
For channel temp. 66° F to 77° F, limit increase to (14)						< 2° F						
For channel temp. > 77° F, limit increase to (15)						< 1° F						

FOOTNOTES

(1) Releases from storage reservoir ahould not cause the TOC concentration at any of the intakes of SWP, CVP, CCWD pumping plant, or urban water treatment plant (ALL INTAKES) to exceed 4.0 mg/L (14-day average).

(2) Incremental increase of TOC concentration at ALL INTAKES should not exceed 1.0 mg/L (14-day average).

(3) Discharge from Bacon Island and Webb Tract is limited to a declining scale if TOC concentration of stored water is higher than TOC of channel water

(4) Chloride concentrations at ALL INTAKES shall not ecxeed 10.0 mg/L.

(5) Operation of Delta Wetlands Project should not cause or contribute to salinity increase at ALL INTAKES if salinity at the intake is at 90% of an adopted standard.

(6) If chloride concentration of stored water is higher than of the channel water, the conbined discharge from storage islands will be limited depending on the incremental differencial.

(7) Modeled or predicted TTHM concentration at ALL INTAKES or the outlet of a water treatment plant should be caused by the Project to exceed 64 µg/ L.

(8) Modeled or predicted bromate concentration at ALL INTAKES or the outlet of a water treatment plant should be caused by the Project to exceed 8 µg/ L.

(9) Stored water will not be discharged if DO is less than 6 mg/L.

(10) Stored water will not be discharged if it would cause the DO of the mixture with channel water to drop less than 5.0 mg/L.

(11) Stored water will not be discharged if the operation would decrease the DO of San Joaquin River between Turner Cut and Stockton to less than 6.0 mg/L.

(12) Stored water will not be discharged in the channels if the temperature differential is more than 20° F .

(13) No discharge of stored water if it will increase the channel water temperature by more than 4° F when the channel water temperture is between 55° F and 66° F.

(14) No discharge of stored water if it will increase the channel water temperature by more than 2° F when the channel water temperture is between 66° F and 77° F.

(15) No discharge of stored water if it will increase the channel water temperature by more than 1° F when the channel water temperture is higher than 77° F.

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M e m o r a n d u m

Date: May 15, 2001

To: Tara Smith

From: Jamie Anderson
Delta Modeling
Office of SWP Planning
Department of Water Resources

Subject: Simulated DOC to Historical DICU Correlations

The purpose of this analysis was to determine statistical correlations between simulated Dissolved Organic Carbon (DOC) concentrations and historical Delta Island Consumptive Use (DICU) data. Ganesh Pandey conducted a Delta Simulation Model II (DSM2) validation study for DOC documented in Chapter 3 of the Delta Modeling Group 2001 Annual Report. Simulation results for DICU covered the time period March 1991-September 1998. This time period covered a wide range of water year types (Table 1). Thus, it was determined that the simulation results provided a data set of sufficient length and variability for a first cut determination of correlation between DOC concentrations and DICU.

Table 1: Water Year Type Designations

Year	SAC 40-30-30
1991	Critical
1992	Critical
1993	Above Normal
1994	Critical
1995	Wet
1996	Wet
1997	Wet
1998	Wet

Simulation results from seven locations were correlated with historical DICU data. The seven locations are Clifton Court Forebay, Santa Fe Bacon Island, Delta Mendota Canal, Contra Costa Canal, Old River Bacon Island, Old River near DMC and Clifton Court, and Los Vaqueros Intake (Figure 1). Correlation coefficients were computed between simulated monthly average DOC concentrations and historical monthly Delta-wide consumptive use values. The correlation coefficients were computed using the CORREL function in Excel that uses the following formula:

$$\rho_{x,y} = \frac{\frac{1}{n}\sum_{n=1}^{n}(x_i-\mu_x)(y_i-\mu_y)}{\sigma_x\sigma_y}$$

where: $-1 \le \rho_{x,y} \le 1$

$\rho_{x,y}$ Correlation Coefficient between data sets x and y

n Number of values in each data set

x, y Two independent data sets (arrays) to be correlated

μ Mean

σ Standard Deviation

If the correlation coefficient, $\rho_{x,y}$, equals zero, there is no correlation between the two data sets. If the correlation coefficient equals 1, the data sets are positively correlated, and large values of one data set are associated with large values of a second data set. If the correlation coefficient equals –1, the data sets are negatively correlated. Large values of one data set are associated with small values of the second data set.

The simulated DOC and historical DICU values were determined to be negatively correlated throughout the system (Table 2). Correlation coefficients were computed for monthly average minimum and maximum simulated DOC concentrations. For the monthly average simulated DOC, the correlation coefficients at the seven locations ranged from –0.55 to –0.70 with an average value of –0.62. The negative correlation indicates that high values of DICU correspond to low concentrations of DOC (Figure 2). Similarly, lower values of DICU correspond to higher concentrations of DOC. Since the correlation coefficients are not exactly equal to negative one, the correlation indicated is a general trend but not a perfect correlation.

Polynomial regression relationships were developed for each of the seven locations (Figure 3 through Figure 9). The regression equation and R^2 values are indicated on each figure. The lack of a strong correlation between DICU and DOC concentrations is further indicated by the R^2 values which ranged from 0.3087 to 0.4991. Improved R^2 values ranging from 0.5195 to 0.6723 were obtained by computing the regressions on monthly averaged DOC and DICU values (Figure 10 through Figure 16).

Table 2: Computed Correlation Coefficients for Simulated DOC and Historical DICU

	Correlation Coefficient		
Relationship	Avg DOC	Min DOC	Max DOC
DOC Clifton Court to DICU	-0.61	-0.37	-0.65
DOC Sante Fe Bacon Isl to DICU	-0.64	-0.52	-0.75
DOC DMC to DICU	-0.62	-0.33	-0.64
DOC CCC to DICU	-0.55	-0.29	-0.63
DOC Old R Bacon Is to DICU	-0.70	-0.59	-0.74
DOC Old R-DMC-CL to DICU	-0.63	-0.35	-0.65
DOC Los Vaqueros to DICU	-0.61	-0.47	-0.47
Average	*-0.62*	*-0.41*	*-0.65*

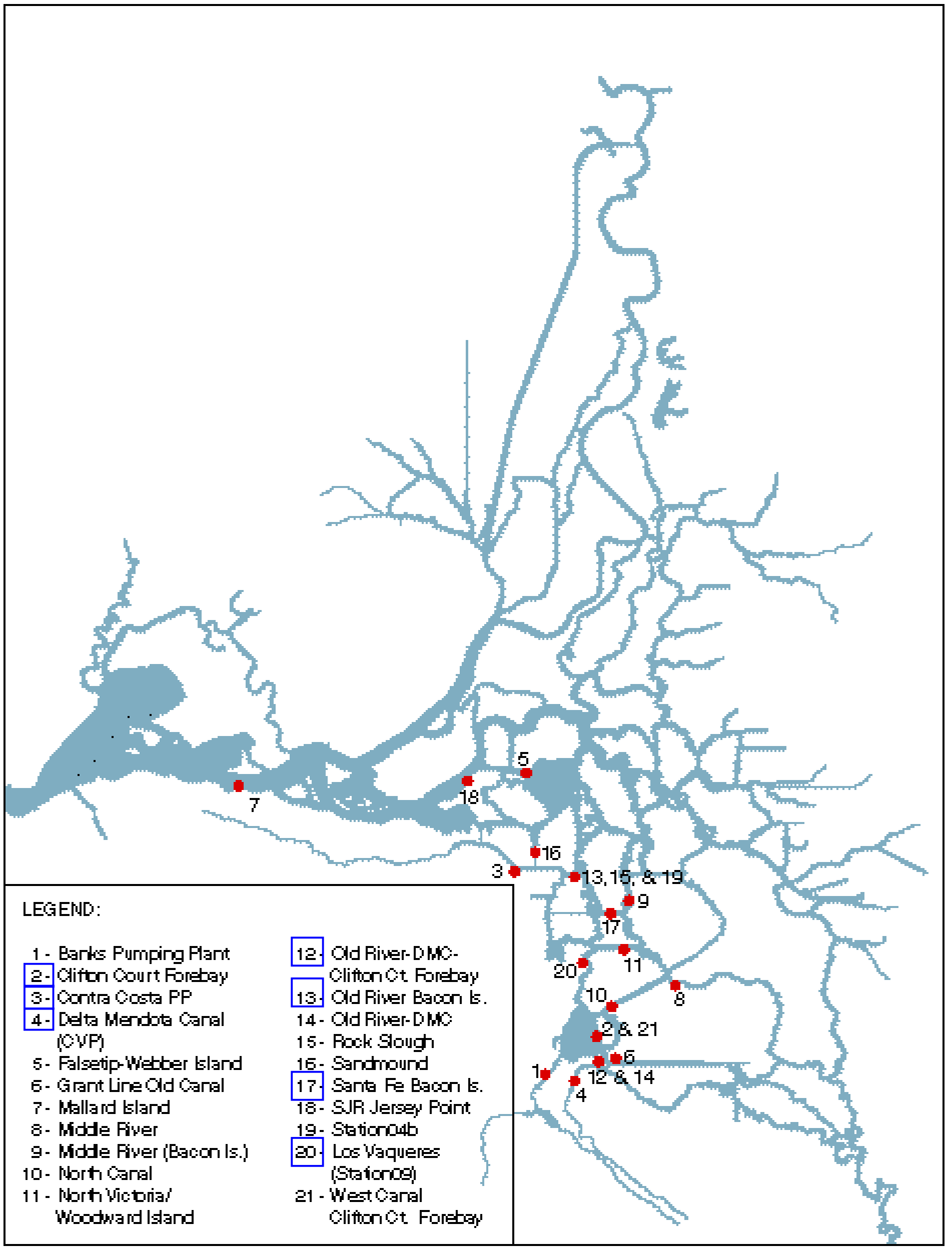


Figure 1: DSM2 Output Locations for DOC Validation Study
Location numbers highlighted in the legend indicate sites utilized in the correlation analysis

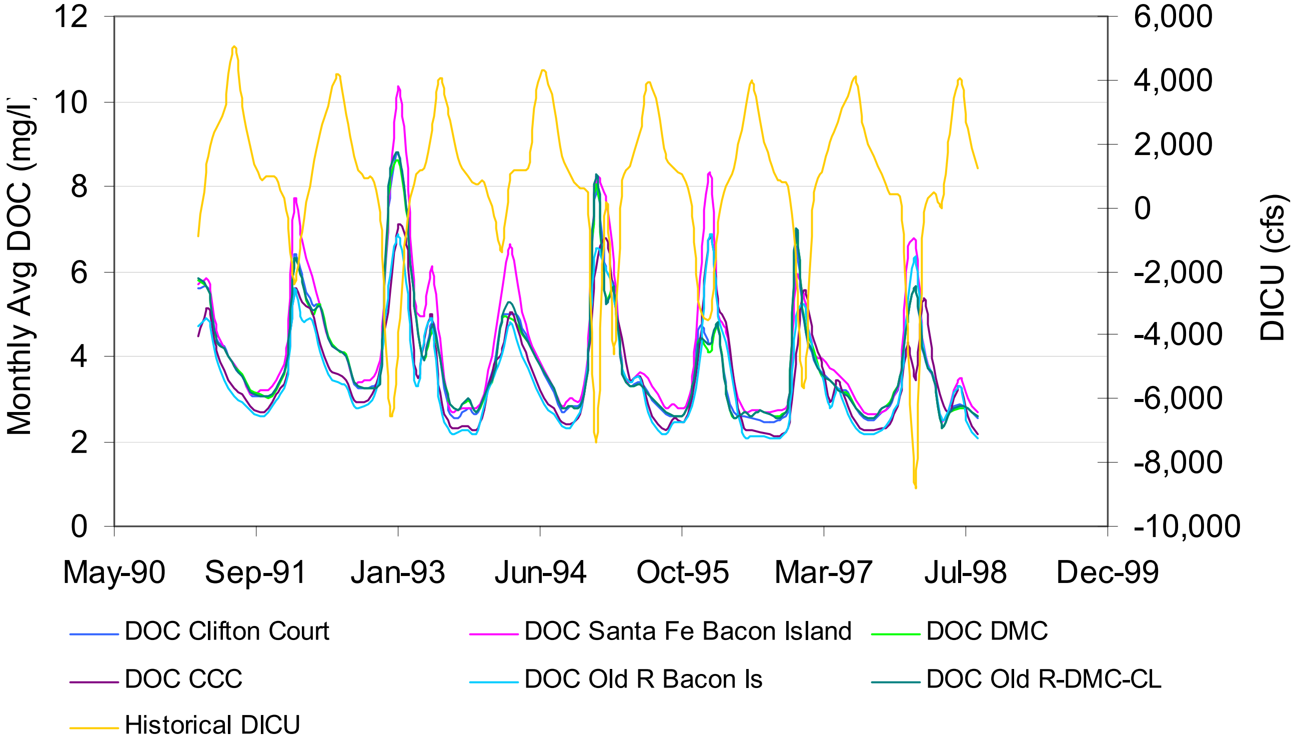


Figure 2: Simulated Monthly Average DOC Concentrations Compared to Historical DICU

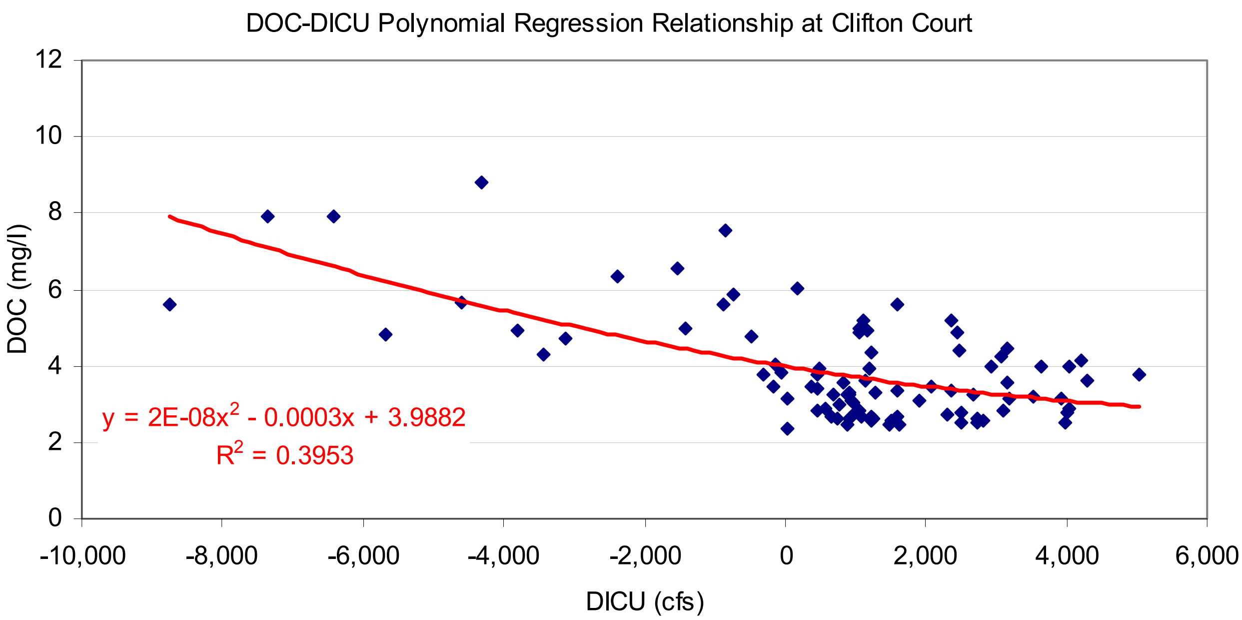


Figure 3: Polynomial Regression Relationship between DOC and DICU at Clifton Court

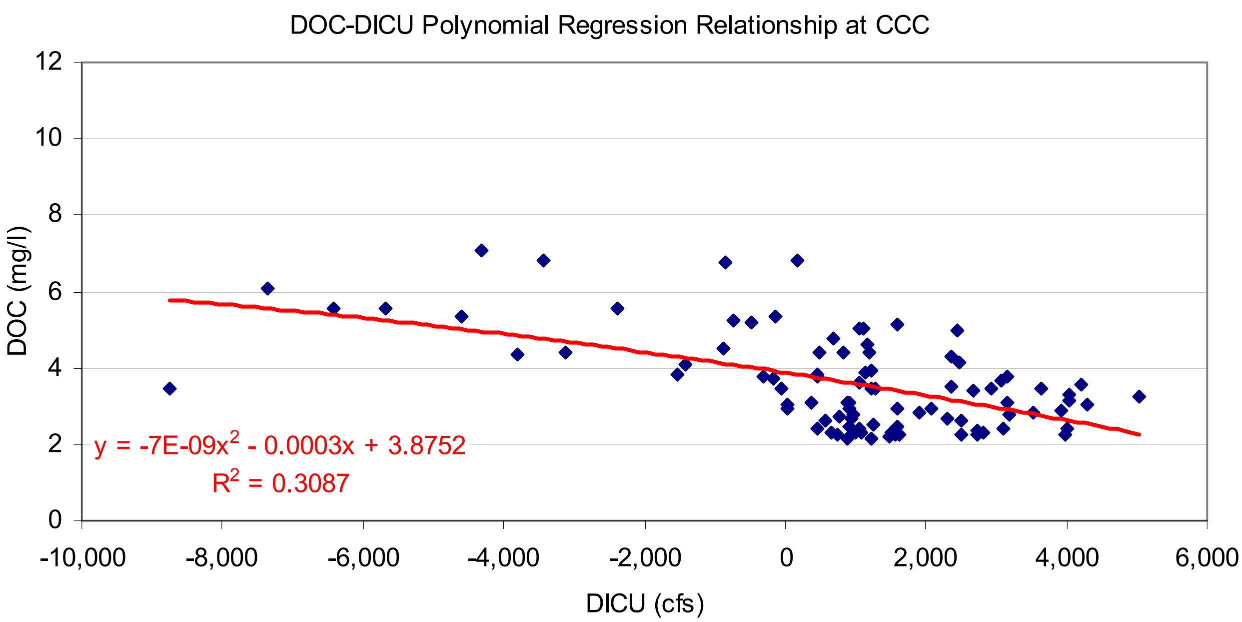


Figure 4: Polynomial Regression Relationship between DOC and DICU at Contra Costa Canal

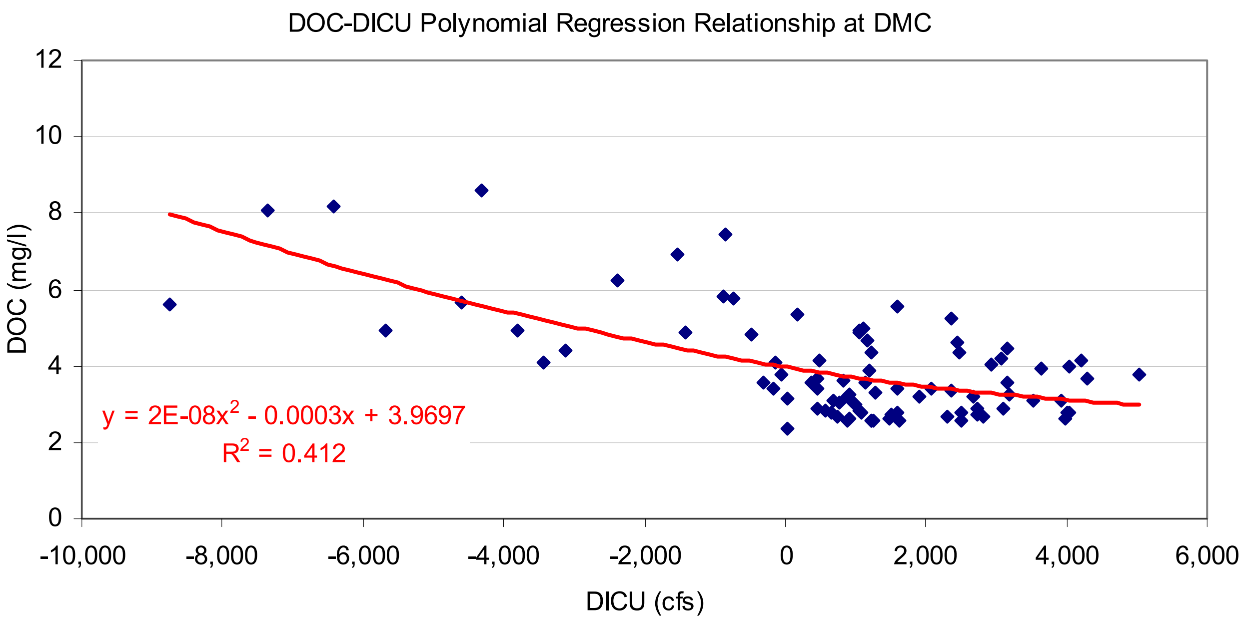


Figure 5: Polynomial Regression Relationship between DOC and DICU at Delta Mendota Canal

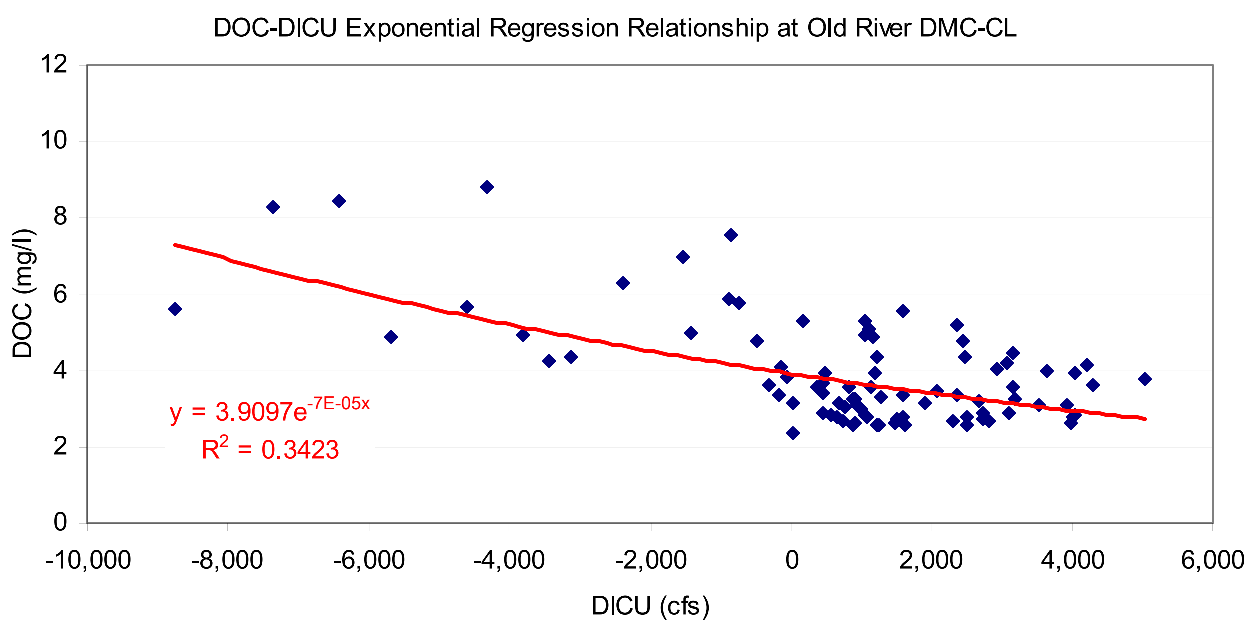


Figure 6: Polynomial Regression Relationship between DOC and DICU at Old River Delta Mendota Canal-Clifton Court Forebay

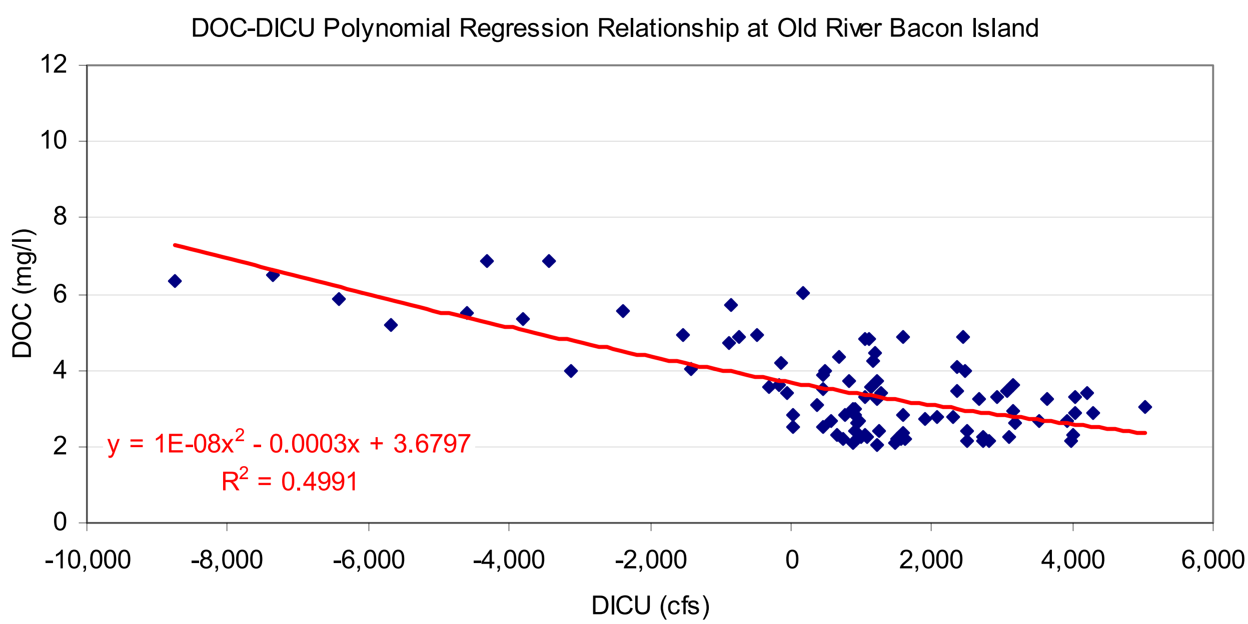


Figure 7: Polynomial Regression Relationship between DOC and DICU at Old River Bacon Island

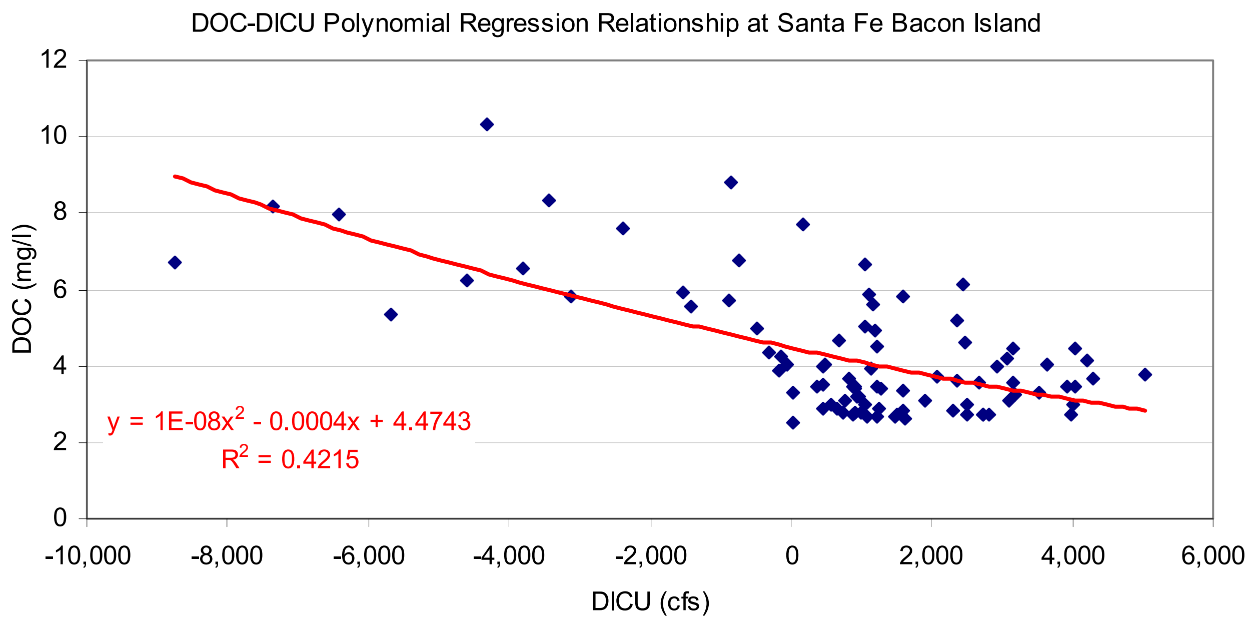


Figure 8: Polynomial Regression Relationship between DOC and DICU at Sante Fe Bacon Island

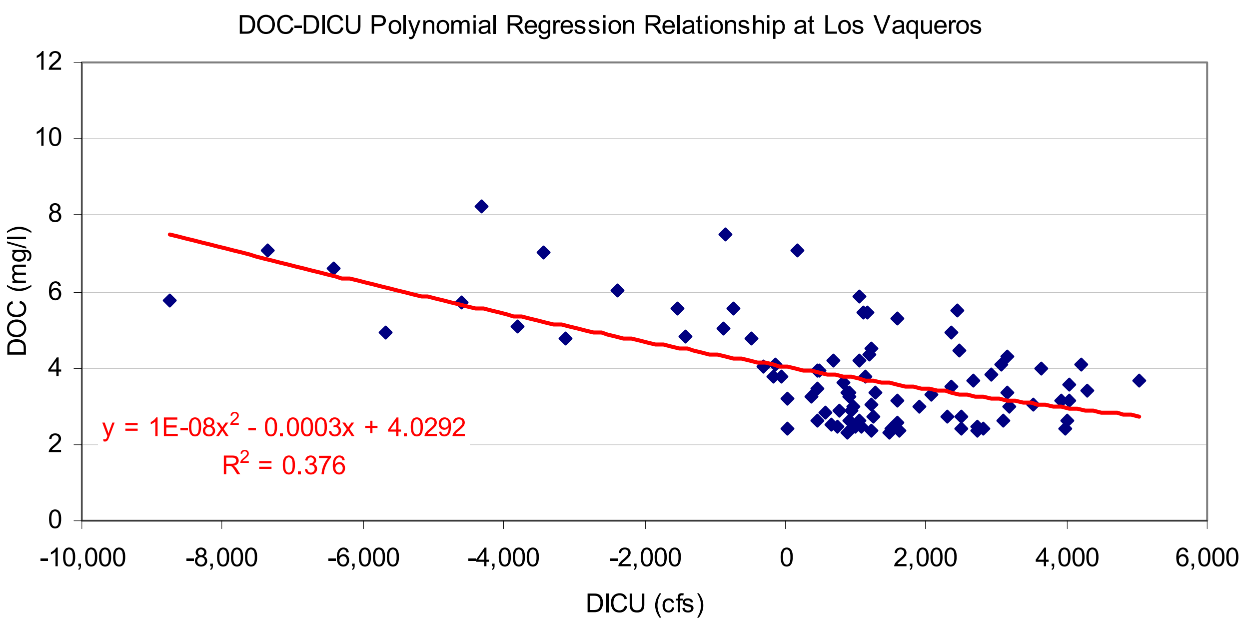
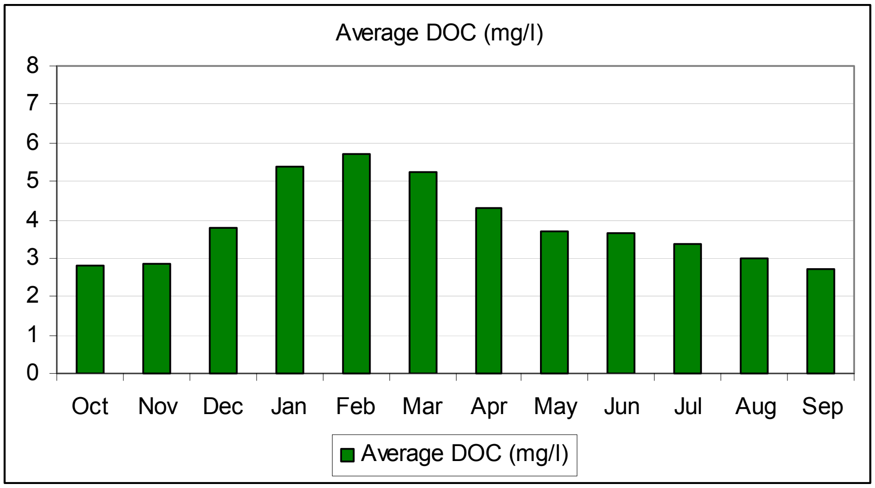
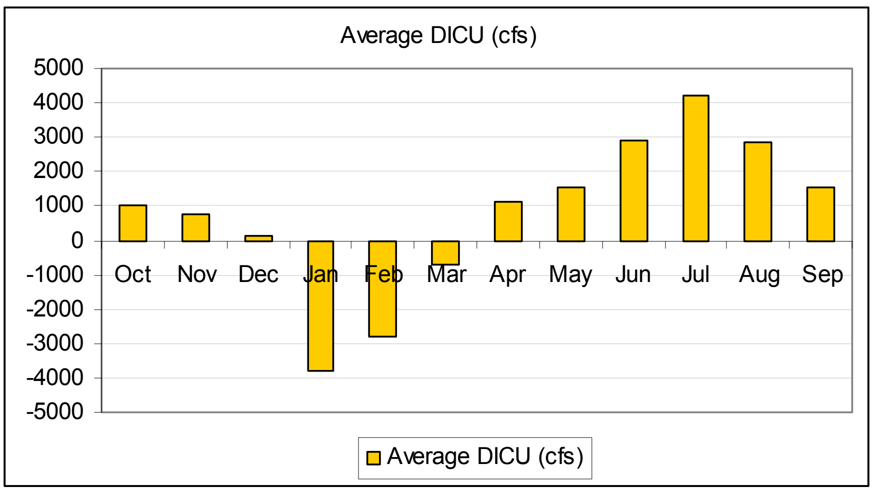


Figure 9: Polynomial Regression Relationship between DOC and DICU at Los Vaqueros





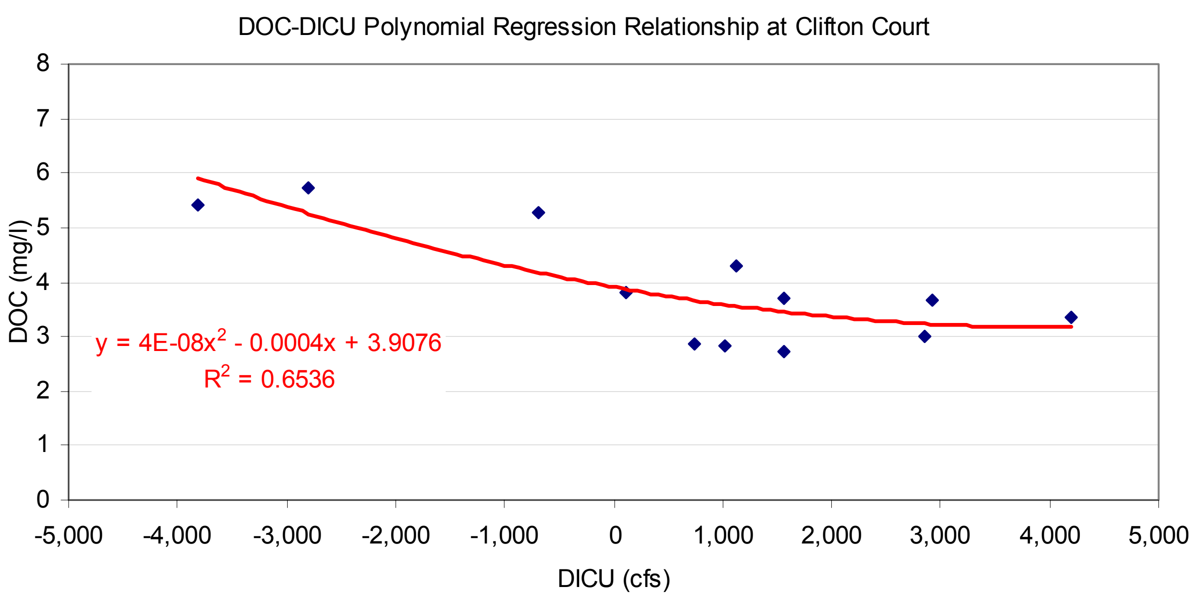
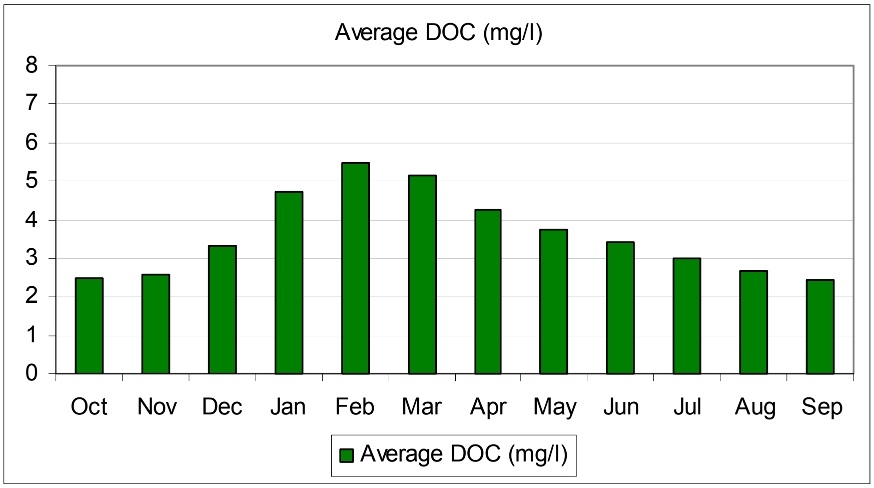
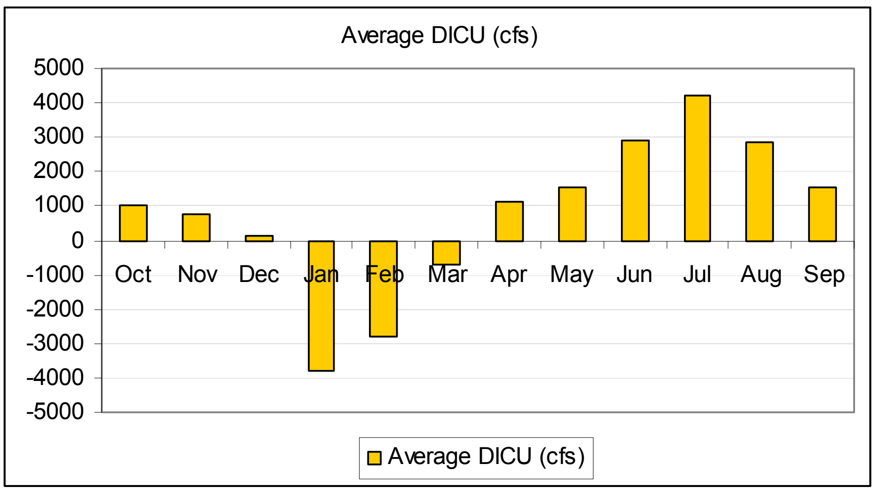


Figure 10: Polynomial Regression of Monthly Average DOC and DICU at Clifton Court





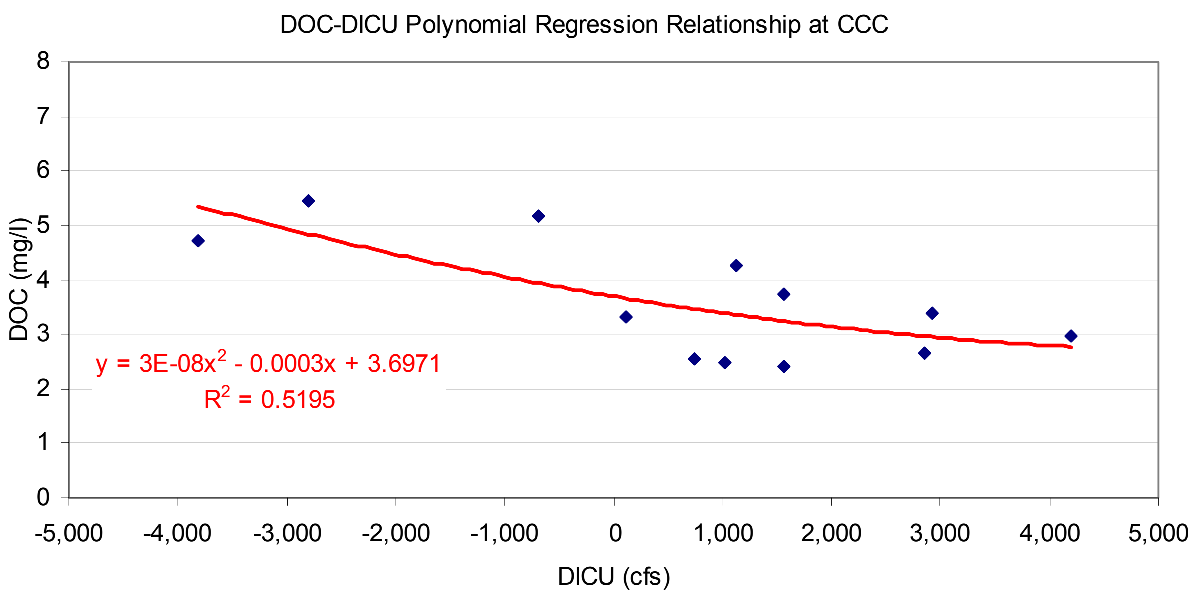
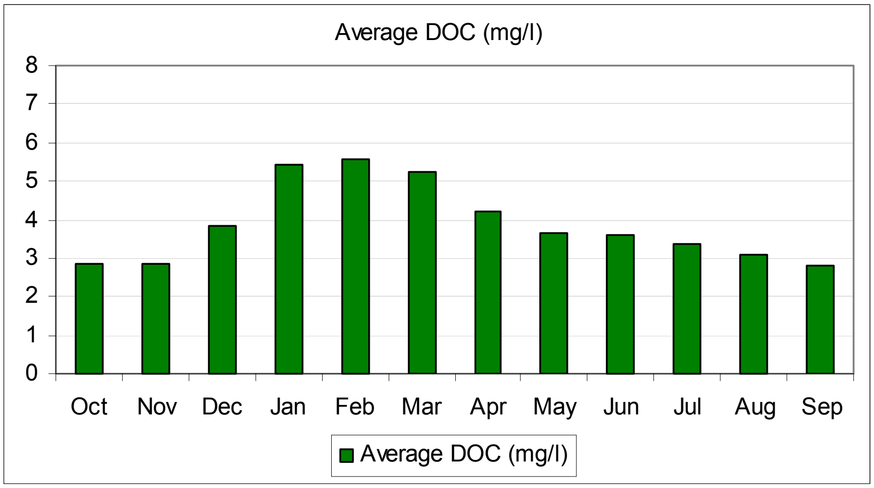
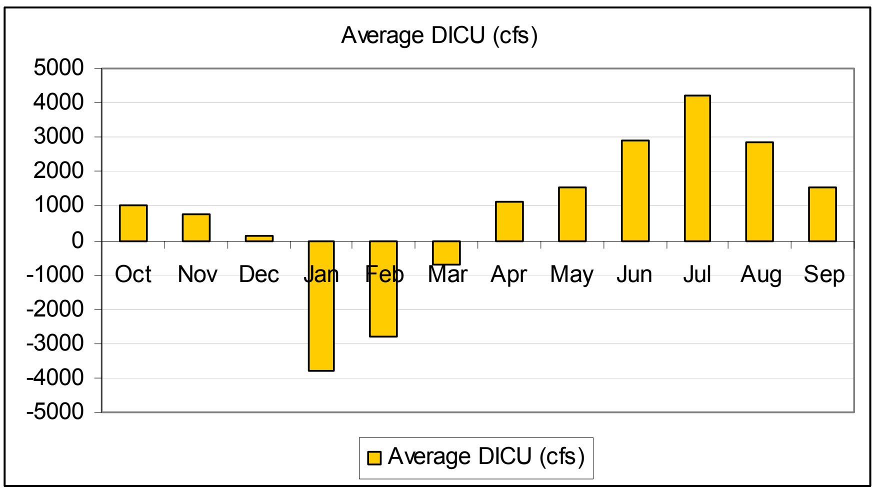


Figure 11: Polynomial Regression of Monthly Average DOC and DICU at Contra Costa Canal





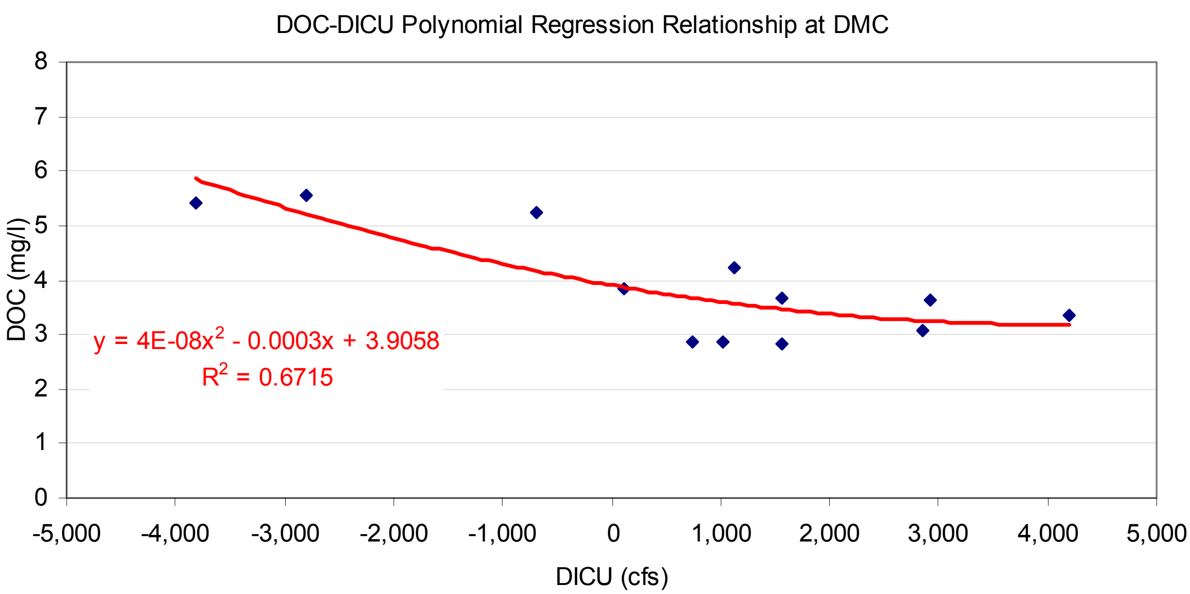
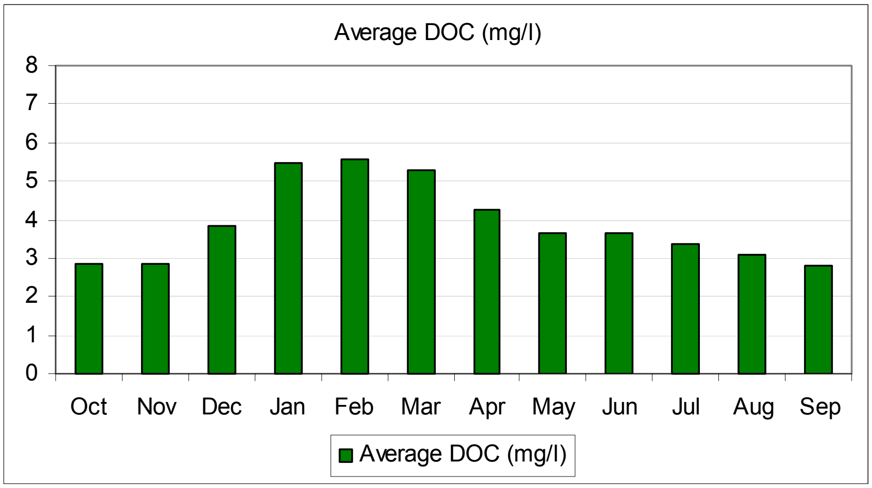
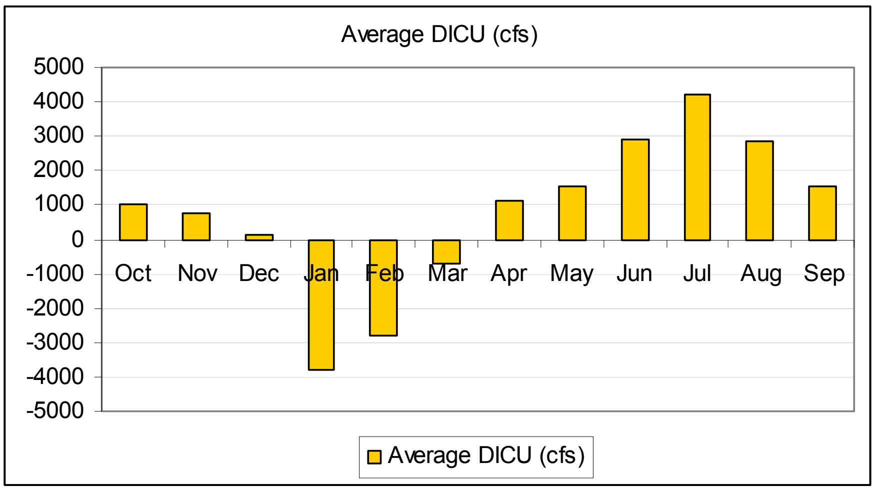


Figure 12: Polynomial Regression of Monthly Average DOC and DICU at Delta Mendota Canal





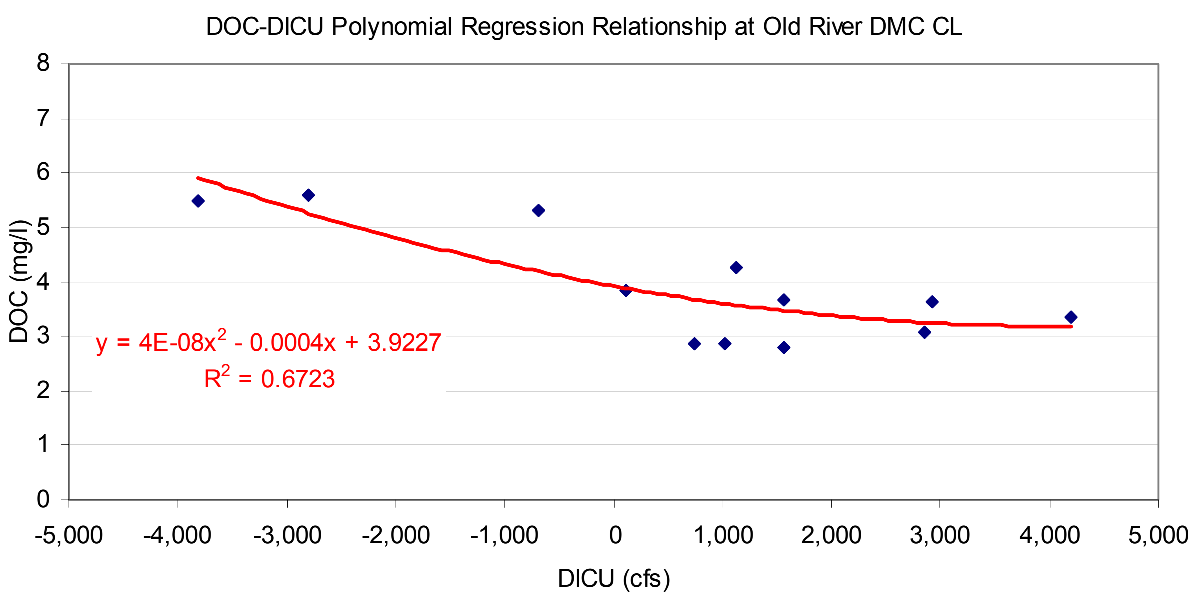
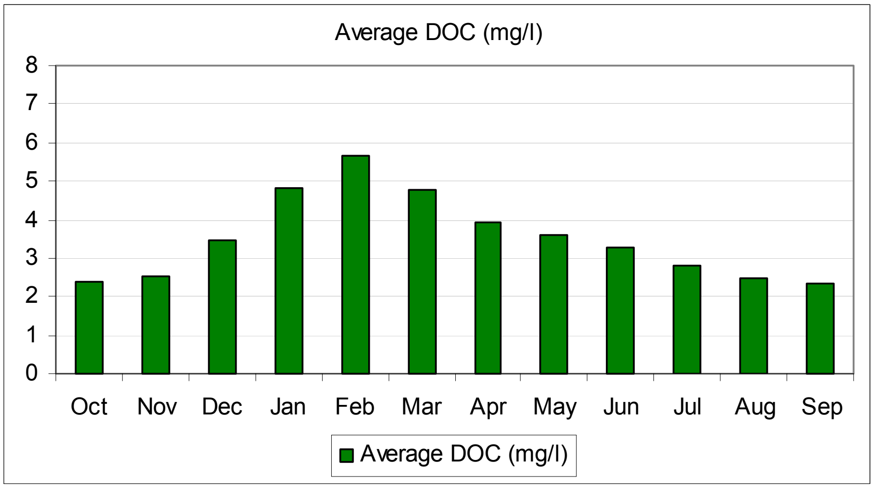
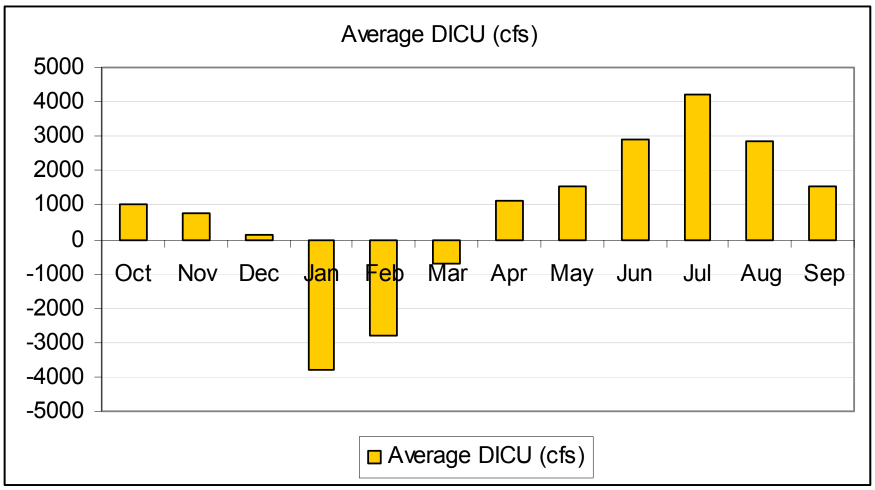


Figure 13: Polynomial Regression of Monthly Average DOC and DICU at Old River Delta Mendota Canal-Clifton Court Forebay





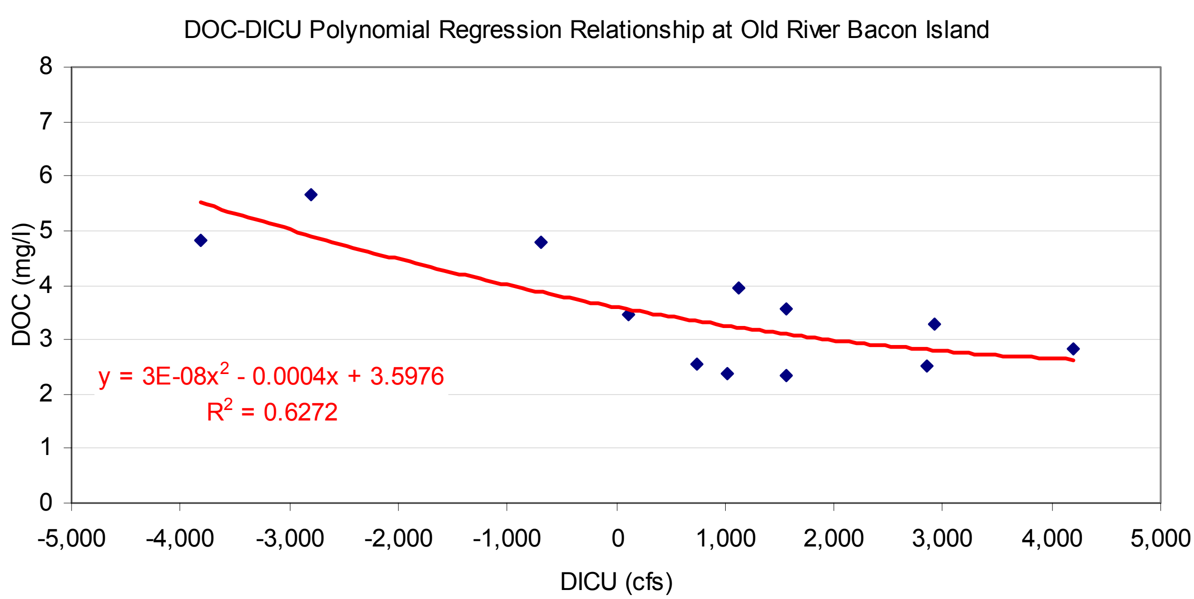
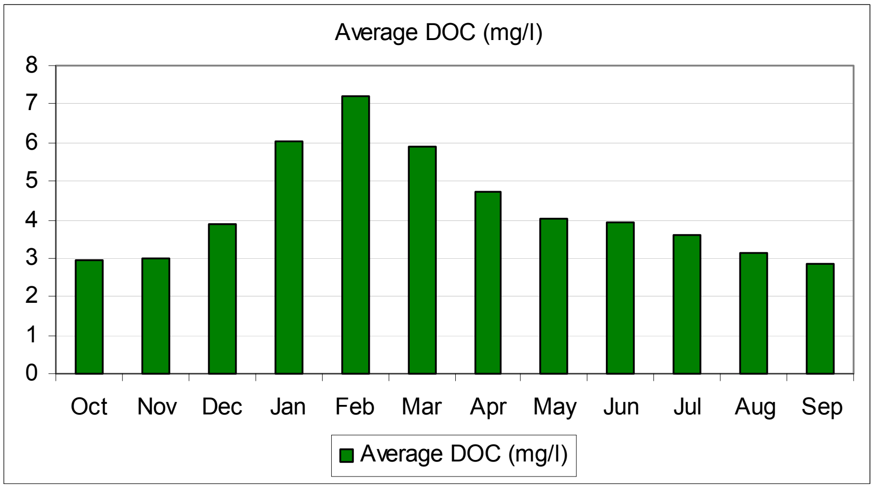
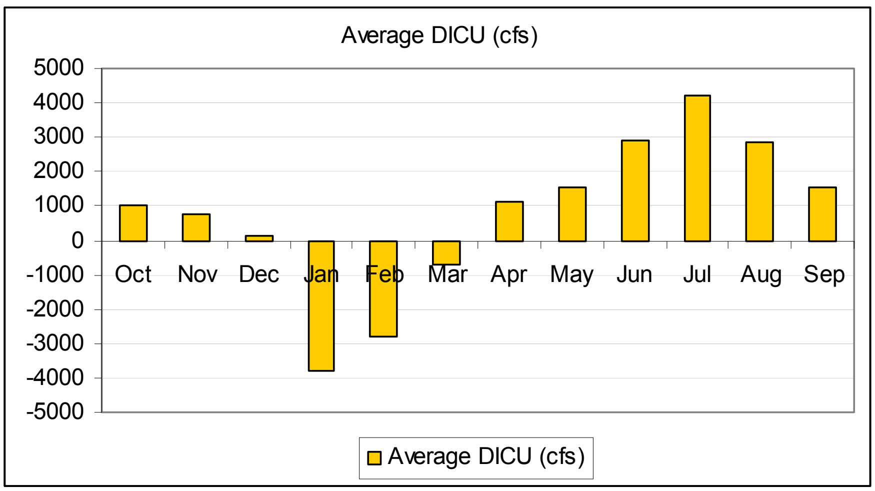


Figure 14: Polynomial Regression of Monthly Average DOC and DICU at Old River Bacon Island





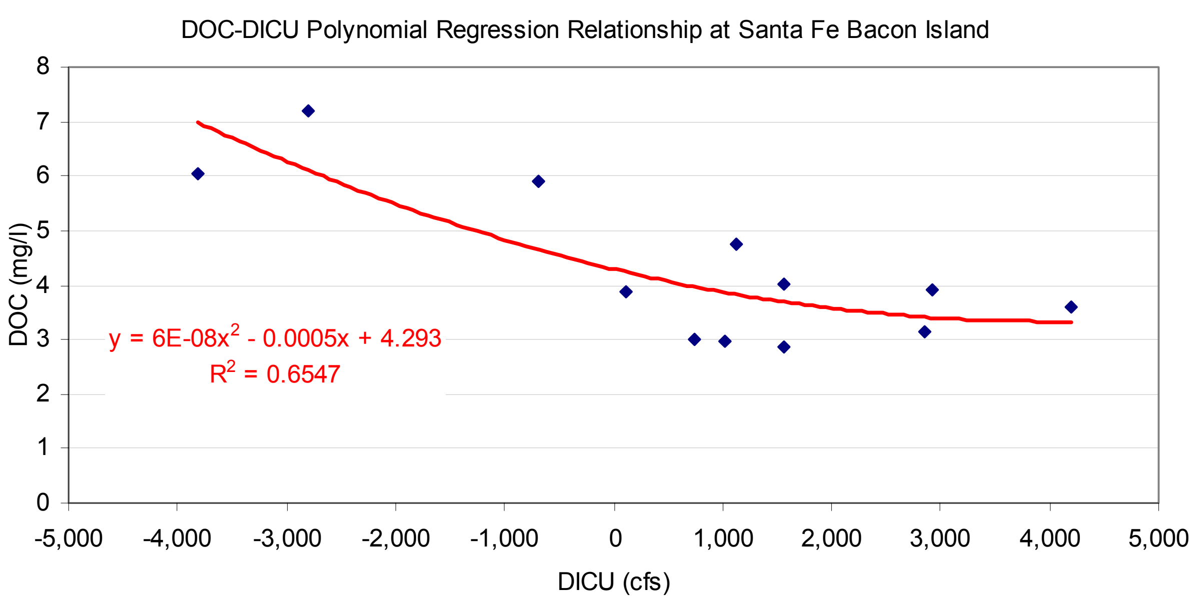
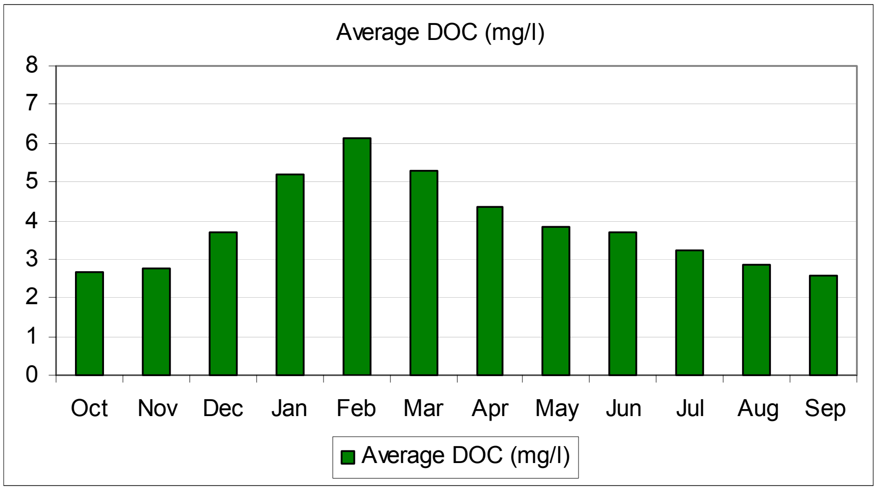
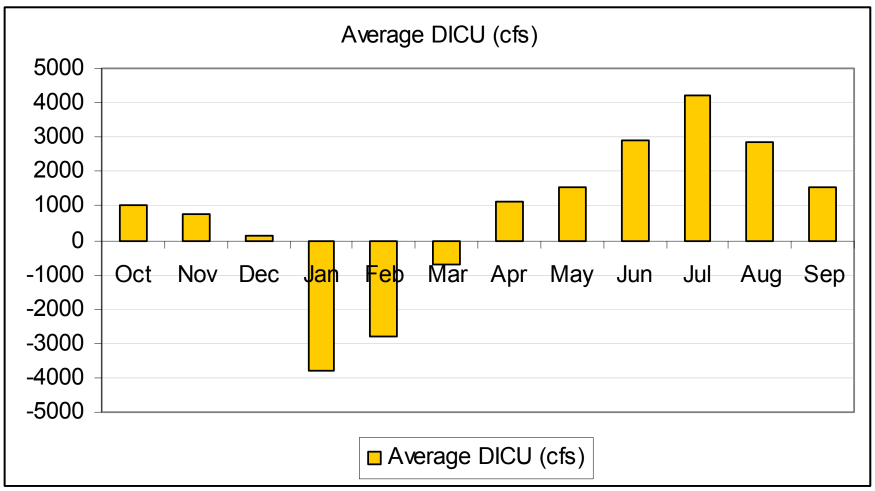


Figure 15: Polynomial Regression of Monthly Average DOC and DICU at Santa Fe Bacon Island





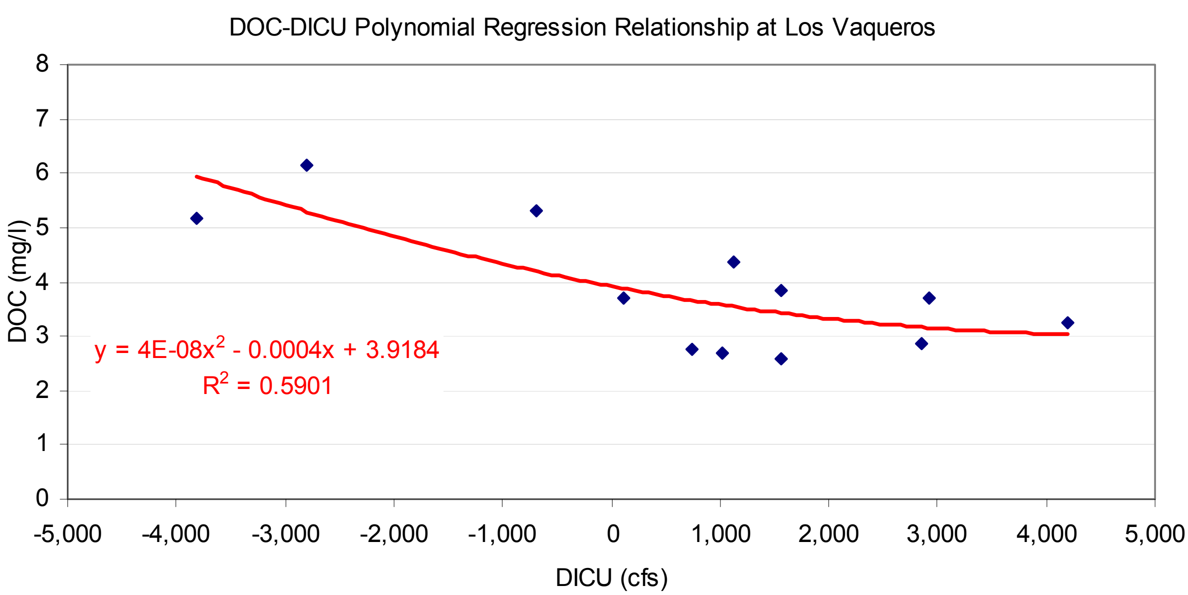


Figure 16: Polynomial Regression of Monthly Average DOC and DICU at Los Vaqueros

M e m o r a n d u m

Date: December 7, 2001

To: Tara Smith

From: Jamie Anderson
Delta Modeling
Office of SWP Planning
Department of Water Resources

Subject: DOC-UVA Correlations

Regressions were computed to determine if there were correlations between simulated DOC and UVA values for the preliminary Delta Wetlands simulations documented by Michael Mierzwa in a DWR internal memo titled "Delta Wetlands Preliminary DSM2 Studies" dated August 26, 2001. Four simulations were conducted for the preliminary Delta Wetlands studies, a base case and three alternative scenarios. The three alternative scenarios represented ranges of return quality for DOC and UVA as shown in Table 1. The DOC and UVA concentrations simulated for the three alternatives were analyzed to determine if a correlation existed between DOC and UVA concentrations.

Table 1: DOC and UVA Concentrations for Alternative Scenarios

Bookend Simulation	DOC (mg/L)	UVA (cm^{-1})
Low	6	0.289
Middle	15	0.686
High	30	1.348

In order to determine if a DOC-UVA correlation exists simulated DOC and UVA concentrations from the three alternative simulations were considered together to cover the range of expected values. Results were analyzed at four locations: Old River at Bacon Island, Old River near Byron, the State Water Project (Clifton Court) and the Central Valley Project (Delta Mendota Canal). The four analysis locations are shown in Figure 1. Several correlation methods were applied to the data, and a linear correlation was determined to have the best fit considering the R-squared values. Linear correlations between DOC and UVA concentrations for each location are shown in Figure 2. Additionally the DOC and UVA data from the four locations were lumped together and a single linear correlation was computed as shown in Figure 3 The computed regression equations and R-squared values for the individual locations and lumped data are summarized in Table 2. For all of the correlations, the R-squared values ranged from 0.8971 to 0.9717. Lumping the data from the four locations provided a correlation with an R-squared value of 0.9373.

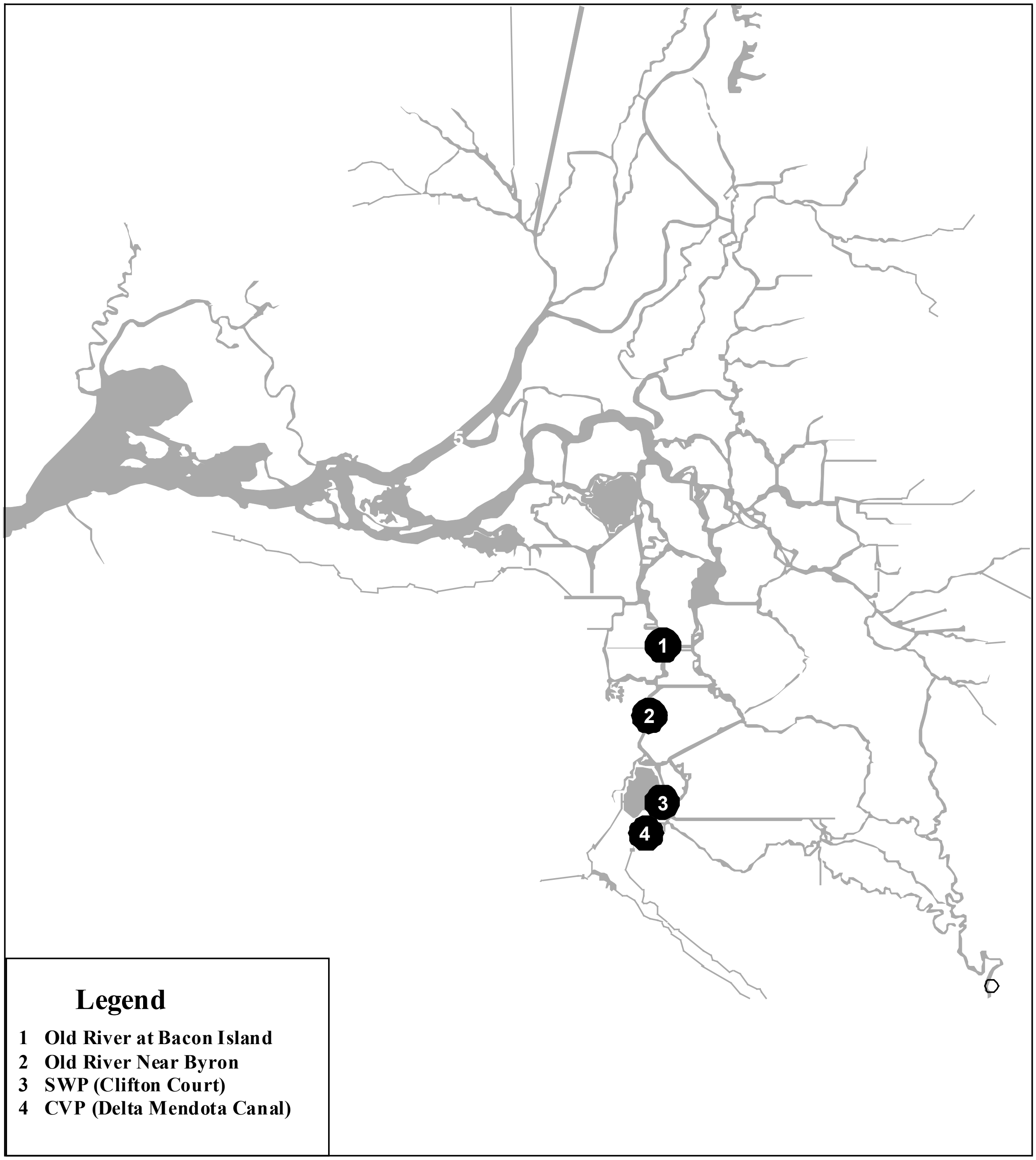


Figure 1: Map of DOC-UVA Correlation Analysis Locations

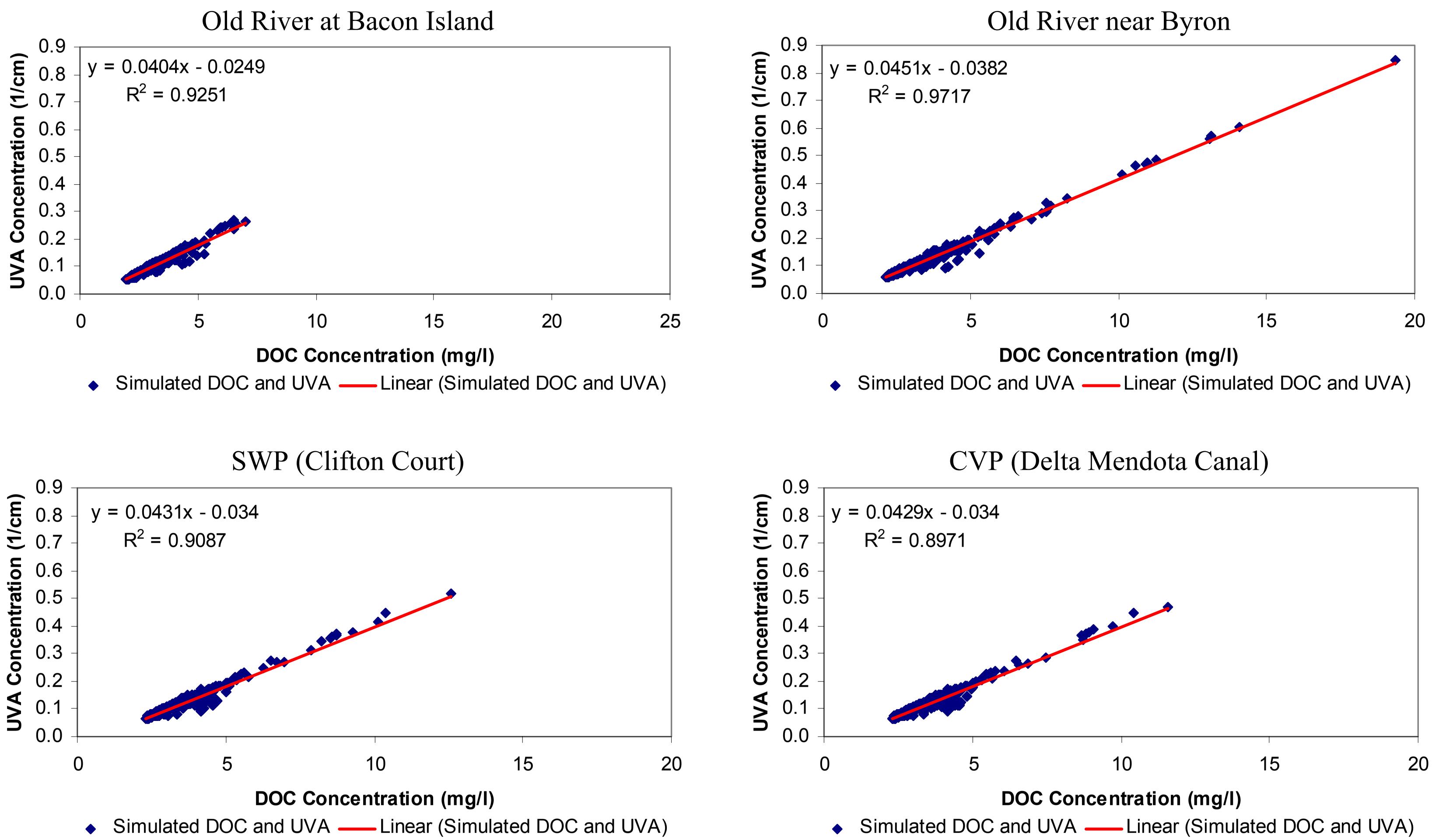


Figure 2: Linear Regressions for DOC and UVA at Four Delta Locations

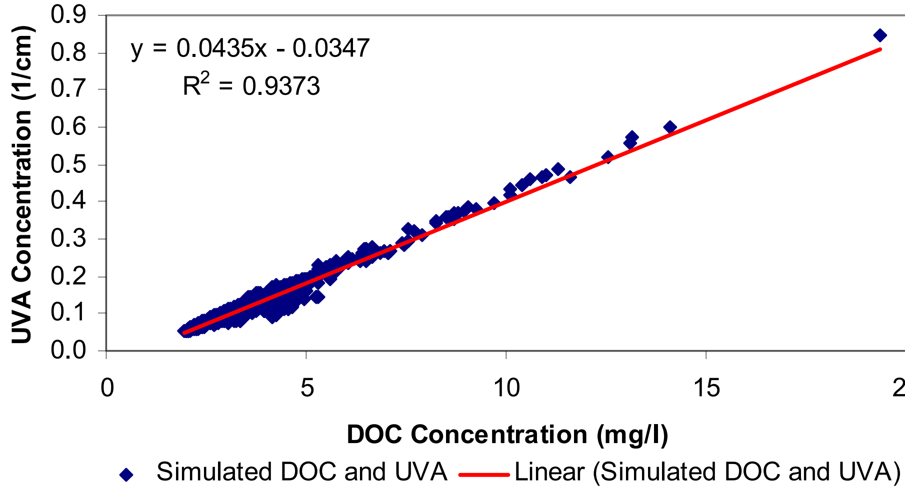


Figure 3: Linear Correlation between DOC and UVA Concentrations Lumping Data from Four Delta Locations

Table 2: DOC and UVA Correlation Equations and R-Squared Values

Location	**Linear Regression DOC and UVA**	**R-Squared Value**
Old River at Bacon Island	UVA = 0.0404*DOC - 0.0249	0.9251
Old River Near Byron	UVA = 0.0451*DOC - 0.0382	0.9717
SWP (Clifton Court)	UVA = 0.0431*DOC - 0.0340	0.9087
CVP (Delta Mendota Canal)	UVA = 0.0429*DOC - 0.0340	0.8971
All Locations	UVA = 0.0435*DOC – 0.0347	0.9373